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Development of New Precipitation Depth, Duration, Frequency Maps for the State of Arkansas

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Final Report

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DEVELOPMENT OF NEW PRECIPITATION DEPTH, DURATION, FREQUENCY MAPS FOR THE STATE OF ARKANSAS

Final Project Report

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1. INTRODUCTION

1.1 Overview

Hydraulic design of highway drainage structures (e.g., bridges and culverts) is often based upon a design rainfall intensity, which is derived from intensity-duration-frequency (IDF) maps. Current IDF maps for highway drainage design in Arkansas were derived from information contained in the National Weather Service (NWS) Technical Paper 40 (TP 40) (Hershfield, 1961), which is also the traditional source of design rainfall information throughout the United States. However, TP 40 was published more than 45 years ago and, although based on the best available data and most appropriate statistical procedures for the time, the depth-duration-frequency (DDF) information contained in the document has become outdated. The Arkansas State Highway and Transportation Department (AHTD) decided to update their rainfall IDF maps by analyzing approximately 50 years of additional rainfall data and using new statistical procedures and regionalization approaches. Therefore, the new maps may be viewed as an update to the previous maps and should be considered to supersede them. The University of Utah was contracted to perform the data collection and pre-processing, frequency analysis, and production of final DDF maps. This report describes the data sources and analysis procedures, and provides a summary of the accompanying products.

1.2 Objectives

The goal of this project was to create a new set of rainfall DDF maps for the State of Arkansas. The outcome of accomplishing this goal is enhanced ability to represent extreme rainfall characteristics in Arkansas to improve design of highway drainage structures. To accomplish the project goal, the following objectives were accomplished:

- A thorough literature review was completed. Past and current approaches to develop DDF maps were reviewed and the state-of-the-practice was established. Studies recently performed in Oklahoma and Texas by the U.S. Geological

Survey (USGS), Michigan by the Michigan Department of Transportation and Michigan Technological University, Alabama by The University of Alabama and Alabama Department of Transportation, and in the mountain west states by the National Weather Service were closely scrutinized to define the methods to use for this project.

- The depths of extreme rainfall in Arkansas were estimated at rainfall measurement stations (gaging stations) for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals, and for durations of 15 and 30 minutes and 1, 2, 3, 6, and 12 hours, and 1, 3, and 7 days.
- Methods of regionalization and spatial interpolation of rainfall estimates were compared and contrasted to identify the appropriate technique to use to define extreme rainfall characteristics at ungaged locations in Arkansas. A spatial smoothing approach incorporating distance from ungaged location and length of record was selected and used.
- The results of this study were compiled in this report, accompanying documents, and GIS datasets with a graphical user interface.

1.3 Overview of Report and Accompanying Documents

The remainder of the report is divided into five parts: Previous Studies, Arkansas Climate, Data Collection and Processing, Frequency Analysis, and Production of Final Products. Each part summarizes the decision process that led to the techniques implemented, briefly describes the techniques, and provides references for further details. The final report is accompanied by a CD containing the raster parameter databases, the ArcGIS project to access the databases, and the VB tool installer. In addition, a map book was produced as a separate document for those not interested in the methods.

2. PREVIOUS STUDIES

In May, 1961, the U.S. Weather Bureau published Technical Paper (TP) 40 (Hershfield, 1961) that was "...intended as a convenient summary of empirical relationships, working guides, and maps, useful in practical problems requiring rainfall frequency data...", and covered the entire conterminous United States. TP 40 describes the rainfall analyses that were performed in that study, and presents isohyetal maps and seasonal variation diagrams for rainfall durations from 30 minutes to 24 hours, and for recurrence intervals from 1 to 100 years. Since its publication, TP 40 has been a standard source of U.S. rainfall information for use by practicing engineers and hydrologists.

By the mid- to late-1970's, it was recognized that for storm durations of less than 1 hour, ratios of sub-hourly to hourly rainfall values which had been published in TP 40 were in need of revision as they had a discernible geographic pattern. This combined to generate support for the publication of the NOAA Technical Memorandum NWS HYDRO-35 in June, 1977 (Frederick et al., 1977). HYDRO-35, as it is commonly known, presents information on hourly and sub-hourly rainfall extremes for the Eastern and Central United States (the 37 states from Texas to North Dakota and eastward). HYDRO-35 contains isohyetal maps of precipitation-frequency values for durations of 5, 15, and 60 minutes at recurrence intervals of 2 and 100 years. It also gives interpolation equations to derive 10- and 30-minute duration values, as well as for recurrence intervals between 2 and 100 years.

Because of the orographic effects caused by the high mountain ranges in the western United States, rainfall characteristics in that region should be expected to have more complex spatial variability than in other regions. Recognizing that TP 40 did not adequately address this issue in the western United States, the NWS developed the NOAA Atlas 2 (Miller et al., 1973). The NOAA Atlas 2 was published in 11 volumes, with each volume being devoted to rainfall in each of the 11 western states. The NOAA Atlas 2 contains isohyetal maps for 6- and 24-hour storm durations, and also presents methods by which depths of rainfall for other durations may be estimated. Like HYDRO-

35, the NOAA Atlas 2 supersedes TP 40 where the two documents may yield differing rainfall estimates.

The ages of the most widely used publications (TP 40, HYDRO-35 and the NOAA Atlas 2) for obtaining information on extreme rainfall characteristics has led to a number of state- and regionally-sponsored studies intended to update those publications. In Washington State, an effort by Schaefer (1990) to support dam safety analyses involved the determination of the annual series of precipitation extremes for durations of 2, 6 and 24 hours. Because of large differences in precipitation characteristics in various parts of Washington, the state was divided into several homogeneous regions. *L*-moments were employed for distribution fitting, and supported the adoption of the generalized extreme value (GEV) distribution. A 1997 study, also to support dam safety analyses, was conducted by the U.S. Geological Survey (USGS) for the State of Montana (Parrett, 1997). Procedures employed in that study were virtually identical to those used in the Washington study.

A study of rainfall frequencies in the Midwest (Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin) was published in 1992 by the Midwestern Regional Climate Center in Champaign, Illinois (Huff and Angel, 1992). Data series employed were based on annual maximum series, but results were presented in terms of partial duration series using conversion factors presented in the report. Only data series containing at least 50 years of record were used. Log-log graphical analyses of the data was performed (as opposed to the common method of fitting a probability distribution), and isohyetal maps were published showing precipitation depths for durations from 1 hour to 10 days and recurrence intervals from 2 months to 100 years.

In 1993, an *Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada* was published by the Northeast Regional Climate Center in Ithaca, New York (Wilks and Cember, 1993). This atlas covered the 12 States of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia. It also included data for locations in the southern parts of the Provinces of Ontario and Quebec in Canada. Partial duration data series were employed, in which the total number of data values were equal to the number of years of record, and data series were modeled using the Beta-P distribution for all durations. The atlas contains isohyetal maps of rainfall depths for recurrence intervals from 2 to 100 years and durations from 1 to 10 days.

Subsequent to the 1993 study, the Northeast Regional Climate Center published a second study in 1995 (McKay and Wilks, 1995) extending the analyses to durations from 1 to 3 hours. This second study performed actual data analyses for these short durations, whereas the first study (Wilks and Cember, 1993) merely presented adjustment factors based on studies in other parts of the country. Actual data analyses led to lower rainfall amounts for a given duration and recurrence interval than did simple adjustments.

The Florida Department of Transportation commissioned two studies of rainfall extremes in that state, with both studies being completed at the University of Central Florida (Wanielista et al., 1996a, 1996b). The first of those studies developed intensity-duration-frequency (IDF) curves on a county-by-county basis for Florida, and also presented maps of parameter values that could be used to generate IDF curves at any desired location in the state. Both annual and partial duration series data values were employed, but study results were presented in terms of annual series values only. Following the lead of an earlier study of rainfall extremes in the State of Louisiana (Naghavi et al., 1991), the log Pearson Type 3 distribution was used for data modeling. IDF curves were presented for durations from 10 minutes to 12 hours and recurrence intervals from 2 to 500 years. The second of the two Florida studies concentrated on longer durations and presented isohyetal maps for durations from 1 to 10 days and for recurrence intervals from 2 to 100 years.

The Texas Department of Transportation recently sponsored the USGS to perform a study of extreme rainfall in that state (Asquith, 1998). The study focused on rainfall durations from 15 minutes to 7 days and recurrence intervals from 2 to 500 years. *L*-moments were used for fitting the generalized logistic distribution to data for durations from 15 minutes to 24 hours, and the GEV distribution to data for durations from 1 to 7 days. Unlike all previous rainfall studies, the Texas one presented contour maps of the parameters of the probability distributions for all durations of interest. These parameters, combined with quantile equations (provided in the report), can be used to estimate rainfall depths corresponding to the desired recurrence interval.

In Oklahoma, the USGS completed a project with support from the Oklahoma Department of Transportation (Tortelli et al., 1999). The methods implemented were nearly identical to those used in the Texas study. The final product was a database for geographic information systems (GIS) in which rainfall depths for selected durations and recurrence intervals were reported on a regular grid. In Alabama, Durrans and Brown (2002) developed an Internet-based rainfall atlas for the state. They selected the GEV distribution and used *L*-moments for parameter estimation purposes. A spatial smoothing algorithm was used to estimate the distributional parameters at an ungaged site of interest. The rainfall atlas was incorporated into a Java-based Internet graphical user interface.

The Hydrometeorological Design Studies Center (HDSC), Hydrology Laboratory, Office of Hydrologic Development, U.S. National Weather Service has updated its precipitation frequency estimates for the Semiarid Southwestern United States. Updated precipitation frequency estimates contained in NOAA Atlas 14 Volume 1 “Precipitation Frequency Atlas of the United States” replace those found in *Technical Paper No. 49* "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller et al., 1964), *NOAA Atlas 2* “Precipitation-Frequency Atlas of the Western United States” (Miller et al., 1973), “Short Duration Rainfall Frequency Relations for California” (Frederick and Miller, 1979) and “Short Duration Rainfall Relations for the Western United States” (Arkell and Richards, 1986) for the semiarid region. The project included data collection and quality control, dataset formatting, regional frequency analyses, frequency distribution selection and fitting techniques, and spatial interpolation with reports and other documentation to follow. The project determined annual al*L*-season precipitation frequencies for durations from 5 minutes to 60 days, for return periods from 2 to 1000 years. For the project, HDSC reviewed and processed all available rainfall data for the semiarid project area and used accepted statistical methods. In particular, the semiarid project was the pilot project in which decisions regarding the methods and format were made that affect subsequent projects. The results are published as Volumes of *NOAA Atlas 14* on the Internet (http://hdsc.nws.noaa.gov/hdsc/pfds/) with the additional ability to download digital files.

3. ARKANSAS CLIMATE

The State of Arkansas is located between 33° and 37° north and 89° and 95° west. The macroscale climate of Arkansas is basically influenced by the seasonal north-south migration of the polar front and its attendant jet stream, similar to other middle latitude locales. During the summer, the polar front is generally north of Arkansas, so relatively warm and moist air with its origin from the Gulf of Mexico will dominate the climate. Occasional cold front passages will result in summer rainfall from these tropical air masses; however the primary control of Arkansas summer climate is the Texas anticyclone which is oriented northeast-southwest. About 90% of the precipitation occurring over Arkansas has its origin from maritime tropical air masses which pass through the state during late spring, summer, and early fall. During the winter, the polar front will be over and/or south of the state which results in cool to cold weather conditions. The continental polar air masses characterized by dry and cold conditions are most common in late fall, winter, and early spring.

The mesoscale weather of Arkansas is linked to its topographical features. Much of the west and north of the state is hilly and mountainous, while in the southern part there are a number of narrow east-west valleys. The Ozark Plateau and particularly the Boston Mountains act as a barrier for moisture moving from the Gulf, so the northern counties receive a reduced quantity of precipitation. On the other hand, enhanced precipitation will occur over the southern parts. In fact, the highest section of Ouachita Mountains receives the largest mean annual precipitation because of orographic lifting.

Arkansas climate is placed in the humid subtropical category of the Köppen classification and it is generally warm and humid, with hot summers and mild winters. The climate of western and northern parts of the state is usually a little cooler with greater temperature extremes, lower humidity and less cloudiness. Average temperatures controlled by latitude decrease from south to north with little variations of maximum or minimum temperatures over the state. Summer monthly temperatures are around 80° F across the state. Maximum temperature of more than 100° F may sometimes occur during

July and August. Winter monthly temperatures vary from approximately 35° F in the north to approximately 45° F in the south. Freezing temperatures are recorded in the northern part of the state during January and February. The average annual temperature for the period of 1900 to 2004 was 60.7° F (National Oceanic and Atmospheric Administration, 2005).

Precipitation in Arkansas is mostly in the form of rain showers. Annual precipitation totals vary from 45 to 55 inches across the state and are fairly evenly distributed throughout the year. The mean annual precipitation map for the United States shows the isohyets are oriented north-south and the precipitation decreases from southeast to northwest of Arkansas. Snowfall occurs mainly in the northwest whereas it is generally light in some parts of southern and eastern Arkansas. Winter and ice storms are rare, but can be severe.

Arkansas experiences on average 100 rainy days per year. Despite abundant rainfall, rain-free periods and droughts occasionally occur. December through January is the wet period in the south; while March, April and May are the wet months in the north. Heavy local rains frequently produce storm depths of 5 to 10 inches; the 100-yr, 24-hour rainfall depth from TP-40 is 8.5 inches in central Arkansas. Although the occurrence of disastrous floods is rare, the flood of 1927 inundated 20% of the State's total area. Depending on the precipitation pattern, the amount of runoff ranges from 12 to 32 inches per year (Freiwald, 1985). Average annual evaporation from shallow lakes ranges from about 36 inches in the northeast to about 44 inches in the southwest (Faransworth *et al.,* 1982). The small spatial variability of Arkansas' rainfall patterns provides preliminary guidance for the regionalization analysis to be performed during the rainfall frequency analysis.

4. RAINFALL DATA COLLECTION AND PROCESSING

4.1 Data Source and Screening

The best data available were obtained for this project and methods for pre-processing and data testing were selected to closely follow procedures used in recent studies by the USGS, The University of Alabama, Michigan Technological University, and the NWS. Rainfall data compiled by the National Climatic Data Center (NCDC) were obtained on CD-ROMs from two third party vendors: Earthinfo, Inc. and Hydrosphere, Inc. All data available within the State of Arkansas were extracted from the CDs and combined with data from adjacent states that were from rain gages located within 50 km (~ 31 miles) of the border of Arkansas. The 50 km boundary was found in previous studies to be sufficient to limit edge effects near the border (Tortorelli et al. 1999). The overall criterion for retaining data in the analysis was the minimum length of record of ten years (either individually or after combining with adjacent gage – see below), and additional duration specific criteria were used as explained below.

4.1.1 Daily Data Characteristics

Daily data were extracted from the EarthInfo CDs containing processed precipitation gage records archived by the NCDC. Files on these CDs were compiled by EarthInfo Inc. in a manner which made them convenient for export into the appropriate programs for analysis. Data collected had been recorded in units of inches per day.

Processing precipitation data for frequency analysis requires addressing missing or accumulated data since they can lead to errors in statistical analysis of the data. To allow for the analysis to approach the population values by extrapolation, criteria for retention of data in the record and eventually retention of the record were set for this project. Criteria were selected to be consistent with the criteria used by the NWS in the preparation of the National Precipitation Frequency Server as described in NOAA Atlas 14, Volumes 1 and 2. For the daily data processing, we used different durations (1-day, 3-

day, and 7-day) than the NWS, so we had to adjust the criteria slightly. For the 1-day annual maxima the criteria were as follows:

- If all days in a month were missing that month was deleted.
- If more than 10 days in a month were missing, and the maximum precipitation for that month was 0.00 inches then the respective month was deleted.
- If 15 days or more were missing in a month, and the maximum for that month was less than 30% of the average 1-day maximum precipitation over the period of record at that station, the month was deleted.

NWS criteria contained guidelines for 2-day, and 4-day durations, but our analysis is being performed for 3-day duration. We chose to use the 2-day criteria for the 3-day duration data. This produced the following criteria:

- If only a single day of data was present for a given month, the month was deleted.
- If more than 10 days in a month were missing, and the maximum precipitation for that month was 0.00 inches then the respective month was deleted.
- If 15 days or more were missing in a month, and the maximum for that month was less than 30% of the average 3-day maximum precipitation over the period of record at that station, the month was deleted.

For the 7-day annual maxima the following criteria were followed:

- If more than 93% of the days in a month were missing, the month was deleted.
- If 50% of the days in the year were missing, and the maximum precipitation for the year was 0.3 inches or less, the year was set to missing.

If 50% of the months in a year were deleted for any duration, the annual maximum for that year was set to missing. In summary, daily data employed for the Arkansas DDF project were available at 379 gaging sites (including sites outside Arkansas). Additional data testing was performed on each of the records (see below) and 45 sites were eliminated from the frequency analysis at later stages. Figure 1 shows the spatial distribution of the 334 daily gages used in the frequency analysis.

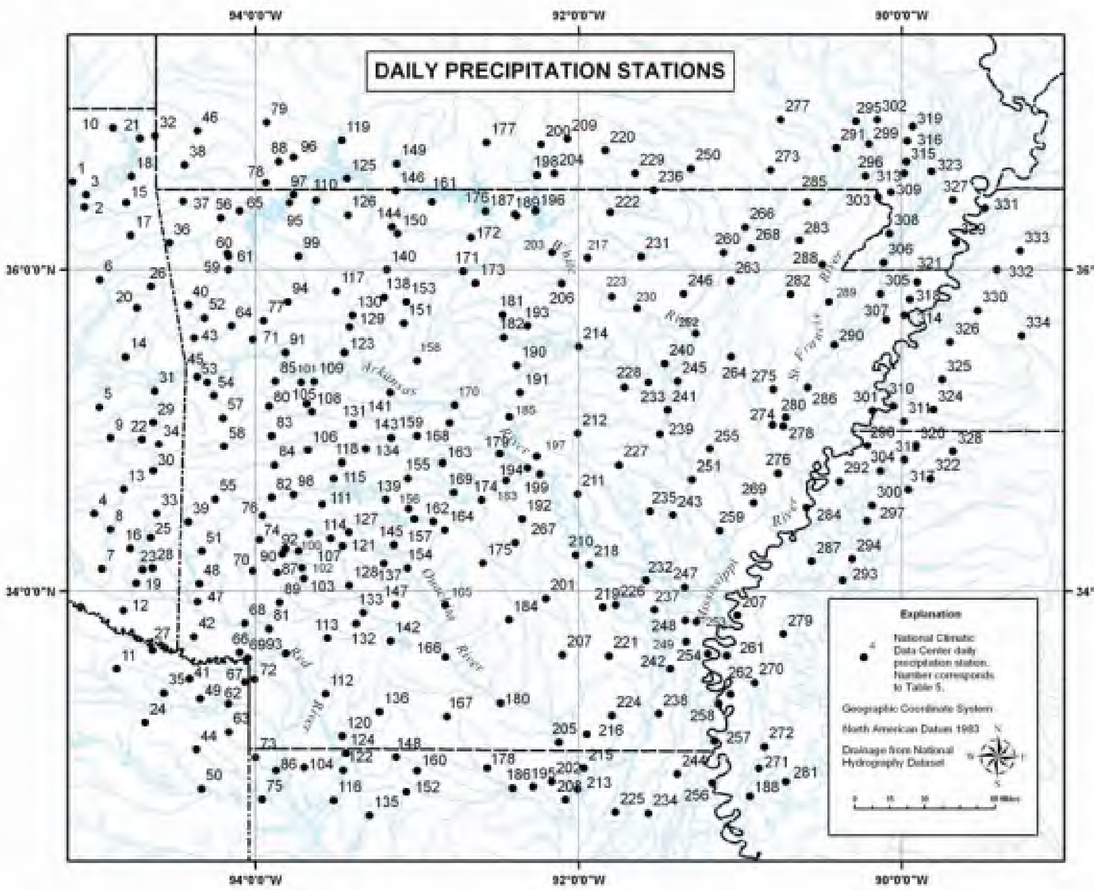


Figure 1. Daily rainfall stations used in the analysis (see Table 5 at end of report).

4.1.2 Hourly Data Characteristics

Hourly data were extracted from the EarthInfo CDs containing processed precipitation gage records archived by the NCDC. Files on these CDs were compiled by

EarthInfo Inc. in a manner which made them convenient for export into the appropriate programs for analysis. Data collected had been recorded in units of inches.

Criteria for retention of hourly data records were again selected to be consistent with the criteria used by the NWS in the preparation of the National Precipitation Frequency Server as described in NOAA Atlas 14, Volumes 1 and 2. For the hourly data the criteria were as follows:

- If the hours available for a month were less than the duration, the month was invalid and the maximum precipitation for that month was set to missing.
- If 240 hours or more were missing in a month and the maximum precipitation for that month was less than or equal to 0.01 inches, the month was deleted.
- If 50% or more hours were missing in a month, the month was deleted.

If 50% of the months in a year were deleted for any duration, the annual maximum for that year was set to missing. In summary, hourly data employed for the Arkansas DDF project were available at 279 gaging sites. Additional data testing (see below) was performed on each record resulting in an additional 150 sites being eliminated. Figure 2 shows the spatial distribution of the 129 hourly gages used in the frequency analysis.

4.1.3 Sub-Hourly Data Characteristics

Sub-hourly (15-minute) data were extracted from the Hydrosphere Data Products Inc. CDs containing processed precipitation gage records archived by the NCDC. Files on these CDs were compiled by Hydrosphere in a manner which made them convenient for export into the appropriate programs for analysis. Data collected had been recorded in units of inches.

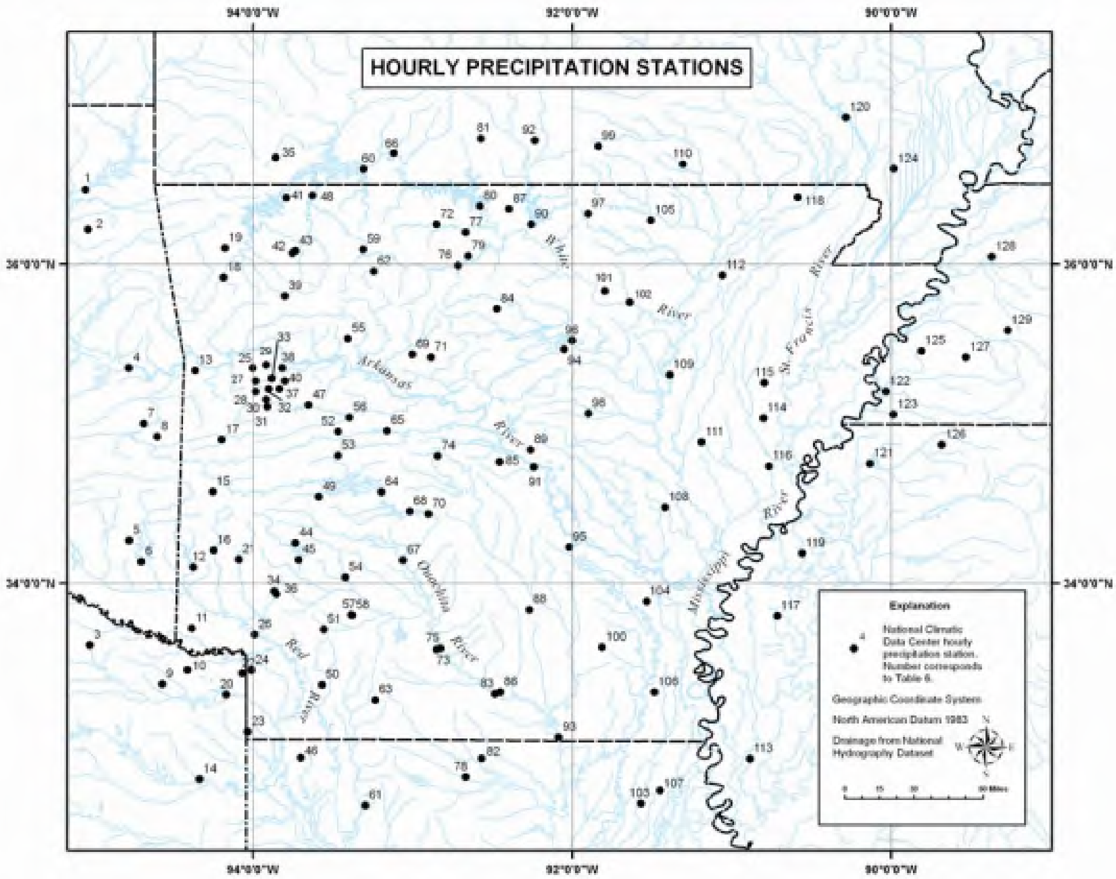


Figure 2. Hourly rainfall stations used in the analysis (see Table 6 at end of report).

Sub-hourly data is prone to have more missing, and accumulated data given the amount of records needed. Employing the criteria used for the daily or hourly records would have eliminated nearly all of the 15-minute data. Consequently, the only criterion used was to discard a year if it did not contain records from January 1st to December 31st.

In summary, sub-hourly data employed for the Arkansas DDF project were available at 81 gaging sites. Additional data testing was performed (see below) on each record resulting in two additional sites being eliminated. Figure 3 shows the spatial distribution of the 79 sub-hourly gages used in the frequency analysis.

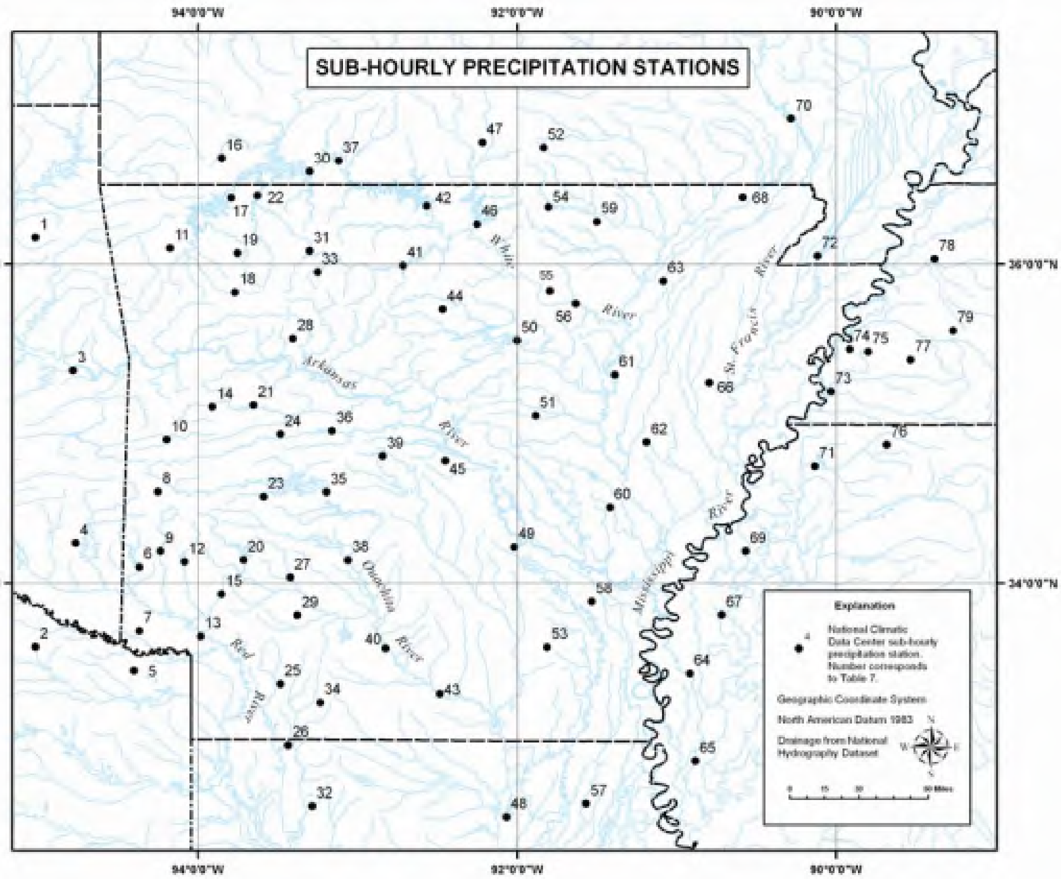


Figure 3. 15-minute rainfall stations used in the analysis (see Table 7 at end of report).

4.2 Data Pre-processing

Once the initial screening of rain records was complete, the second stage involved several pre-processing steps. One of the primary steps was combining records from nearby rainfall stations into a single record with longer duration and more complete data. To be consistent with NWS protocol, records from rain gages located within 5 miles of each other and within 100-ft elevation were targeted for integration. Records identified to meet these criteria were scrutinized manually and decisions were made to integrate the records if it lengthened the record or increased the data coverage. Otherwise, the records remained separate and both would be used in the subsequent analysis. In total, 29 groups of gages were combined for the daily data, 12 groups for the hourly data, and none for 15-minute data. Subsequent tests for homogeneity were performed and verified that the combination of the records did not introduce nonhomogeneities into the record.

Once the record integration was complete, the next step was to compute the annual maxima series (AMS). The choice for the annual series (instead of the partial duration series (PDS)) was based on the observation that highway drainage design in Arkansas is typically based on storm recurrence intervals of at least 10 years. It is generally recognized that analyses based on AMS and PDS yield results that are essentially the same for recurrence intervals of 10 years or more. Moreover, the modeling of annual series is simpler and is the most appropriate for this project. The AMS for each gage was determined for the following durations: 7-day, 3-day, and 1-day (based on daily rainfall data), 24-hr, 12-hr, 6-hr, 3-hr, 2-hr, 1-hr (based on hourly data), and 60-min, 30-min, and 15-min (based on 15-minute data).

There are three possible choices to define the duration of a year: (1) calendar year - January 1 to December 31, (2) water year – October 1 to September 30, or (3) the climatic year – September 1 to August 31. Previous studies suggest the choice does not affect results significantly; therefore, for simplicity we chose to compute the AMS for years corresponding to January 1 to December 31.

4.3 Data Testing

Checks were made for outliers and tests were performed to ensure that data met the fundamental statistical criteria of randomness, homogeneity, and stationarity. If data failed a particular test appropriate corrective measures were considered as described below or the record was removed from the pool used for the subsequent frequency analysis. The data testing involved the following four steps:

1. Identify and remove outliers
2. Test for randomness
3. Test and correction for trends/stationarity (abrupt and gradual)
4. Test for spatial homogeneity and assessment of regionalization approach.

4.3.1 Outliers

Testing and correction for outliers was divided into two steps. The first step was to test for gross outliers using thresholds defined for each duration:

- 7-day: $0 < R < 20$ inches
- 3-day: $0 < R < 15$ inches
- 1-day: $0 < R < 10$ inches
- 24-hr: $0 < R < 10$ inches
- 12-hr: $0 < R < 9$ inches
- 6-hr: $0 < R < 8$ inches
- 3-hr: $0 < R < 6$ inches
- 2-hr: $0 < R < 5$ inches
- 1-hr: $0 < R < 4$ inches
- 60-min: $0 < R < 4$ inches
- 30-min: $0 < R < 3$ inches
- 15-min: $0 < R < 3$ inches

These thresholds were selected to approximately represent the 100-yr rainfall depth from TP 40 for the specified duration. If an AMS contains a value that is greater than the threshold the raw data was inspected closely to ascertain the reason for the exceedance and a determination was made to either accept the data as real or to delete it and replace with the 'missing' designation. Nearby records were used to corroborate anomalies. Several gross outliers were identified, but all were verified by comparison to adjacent gages; therefore no adjustments were made to the AMS.

The second step was to statistically identify outliers using Rosner's test. Due to the normality assumption of Rosner's test, the AMS was log-transformed and then tested for normality at the 10% significance level. Rosner's test also requires a minimum sample size of 25. If a record did not have 25 years the Dixon and Thompson test was performed instead. Initially three extreme points were tested, and if all three were identified as outliers then the number was increased by one, and the test re-run. This incremental process was repeated until enough outliers were included in the test to include all detected. Recent developments in statistical modeling of hydrologic data have shown that, when trying to predict large quantiles (large precipitation amounts), identification of low outliers is important. On the other hand, when trying to predict small quantiles, identification of high outliers is important (Klemes, 1986; Moon and Lall, 1994; Durrans, 1996; Wang, 1997). Since interest is focused on large quantiles for this project, testing of data series for the presence of low outliers was performed (we assumed the gross outlier check would identify the extreme high data errors). As with the check for gross outliers, all identified outliers were checked by manual inspection of records.

4.3.2 Randomness

To test for randomness, we used the Runs Test described by Kottegada (1997). Most other studies reviewed for this project did not include a test for randomness, but instead assumed the data to be random if they satisfied outlier and trend tests. But we decided to perform a simple test for randomness to identify potentially important biases. On average 13% of the daily records, 14% of the hourly records, and 17% of the 15-minute records were determined to have non-random characteristics. To be consistent with other studies we decided not to eliminate these records from further analysis, but instead to make a note and if subsequent tests did not indicate a problem the AMS would be retained in the frequency analysis.

4.3.3 Homogeneity

The homogeneity tests were divided into two parts. First, the AMS was checked for abrupt or episodic changes and then the presence of gradual trends was tested. Plots (bar charts and line graphs of the AMS) were created and visually assessed for nonhomogeneous characteristics due to abrupt or episodic changes. The plots were closely inspected for all gages that had data combined with other gages. We looked for changes in central tendency over time and changes in the spread of data over time – any changes identified were carefully checked and physical reasons for the observed changes were sought. For those series that visually suggested an abrupt or episodic change, the Mann-Whitney U test (also known as the Wilcoxon Rank Sum Test) was performed.

For the second part of the temporal homogeneity test, we tested for secular trends (monotonically increasing or decreasing trends) using the Mann-Kendall nonparametric test and Spearman-Conley test. For each identified trend X-Y scatter plots were created and linear regression performed and slope of regression tested for significance as an additional verification. All homogeneity tests described above were performed at the 10% significance level. Data sets identified as nonhomogeneous were inspected and removed if non-random trends were apparent.

4.4 Summary

The data available for analysis far exceeded the data pool used in producing TP-40, HYDRO-35, and other existing DDF data products. For example, Table 1 presents a comparison of the number of stations used to produce TP-40 and the number used for the revised DDF production. Not only are many more stations available, but the record lengths are also much longer (Table 2). The increase in data quantity improves accuracy of the quantile estimate, increases the spatial resolution improving the representation of spatial variability, and in general reduces the uncertainty.

Table 1. Comparison of number of stations used for frequency analysis

Recording Interval	TP-40	Revised Arkansas DDF
Daily	~130	334
Hourly	~20	129
15-minute	0	79

Table 2. Comparison of average length of record

Recording Interval	TP-40	Revised Arkansas DDF
Daily	15-47	48
Hourly	14	28
15-minute	0	21

5. FREQUENCY ANALYSIS

The objective of frequency analysis is to estimate how often a specified event will occur (Hosking and Wallis 1997). It is a general procedure that can be applied to any type of data. When applied to hydrologic data (e.g., rainfall, runoff) frequency analysis can be divided into two categories: those applied at sites where rainfall or runoff data are available and those that can be applied at sites without data. The second category, termed regionalization, seeks to (1) improve at-site rainfall characteristics using nearby gages and (2) provide the capability to estimate rainfall characteristics at ungaged sites. Common regionalization approaches were reviewed by Hosking and Wallis (1997) including the "index-flood" procedure, hierarchical regions, fractional membership, region of influence, mapping, and Bulletin 17B. The regionalization approach adopted for Arkansas is similar to the methods implemented for Oklahoma, Texas, and Alabama. The underlying assumption is that the parameters of the distribution selected to model the frequency of annual maxima can be expressed as spatially continuous variables.

The regionalization approach used for Arkansas rainfall had seven steps: (1) calculate *L*-moment statistics at each site and each duration using unbiased estimators, (2) determine appropriate distribution for statistical*L*-frequency modeling, (3) compute corrected at-site mean depth accounting for fixed-interval sampling, (4) average coefficient of *L*-variation and *L*-skewness for all durations at each site, (5) compute corrected *L*-scale from the product of the corrected mean depth and the duration-averaged coefficient of *L*-variation, (6) calculate the parameters of the selected distributions at each site, and (7) contour quantile estimates using a spatial smoothing approach.

5.2 At-Site *L*-Moments

L-moments are alternatives to traditional moments to describe the shape of probability distributions. A detailed description of *L*-moments is contained in Hosking and Wallis (1997). *L*-moments in general are given by

$$\lambda_{r+1} = \sum_{k=0}^{r} \frac{(-1)^{r-k}(r+k)!}{(k!)^2(r-k)!}\beta_k \tag{1}$$

where an unbiased estimate of the probability weighted moment β_r is computed from the following

$$b_r = n^{-1}\binom{n-1}{r}^{-1}\sum_{j=r+1}^{n}\binom{j-1}{r}x_{j:n} \tag{2}$$

$x_{j:n}$ = ordered values of the random variable x (rain depth) where x_1 is the largest observation and x_n is the smallest.

The mean, scale, coefficient of variation, skewness, and kurtosis of a distribution estimated using equation 1 are expressed by the following L-moments (λ_r) and L-moment ratios (τ_r)

$$\text{Mean} \equiv \lambda_1 \tag{3}$$

$$L\text{-scale} \equiv \lambda_2 \tag{4}$$

$$\text{Coefficient of } L\text{-variation } (L\text{-CV}) \equiv \tau_2 = \frac{\lambda_2}{\lambda_1} \tag{5}$$

$$L\text{-skewness} \equiv \tau_3 = \frac{\lambda_3}{\lambda_2} \tag{6}$$

$$L\text{-kurtosis} \equiv \tau_4 = \frac{\lambda_4}{\lambda_2} \tag{7}$$

For this project, L-moments and L-moment ratios were obtained for each site and duration using the unbiased estimators presented in Hosking and Wallis (1997).

5.3 Probability Distribution Selection

Selection of a suitable probability distribution to model extreme rainfall values can be performed using a number of approaches. Some of them are simple graphical methods such as plotting data on probability paper. Other methods are based on statistical goodness-of-fit tests and physical/statistical considerations. Recently the use of moment ratio diagrams has emerged as a powerful technique to select suitable probability distributions. The moment ratio diagram is simply a graph of the relationship between skewness and kurtosis characteristics of candidate probability distributions. Although moment ratio diagrams can be constructed using either conventional product moments (the coefficient of skewness and coefficient of kurtosis), Vogel and Fennessey (1993) the use of *L*-moments is preferable. However, regardless of the type of diagram employed, one plots the theoretical relationships for several candidate distributions on the diagram, and one also plots points computed on the basis of available data samples on the same diagram. The task then becomes one of identifying that distribution which appears to best agree with the pattern of the data points.

For this project, *L*-moment ratio diagrams were constructed for all durations. Interpretation of the diagrams suggested both the generalized extreme value (GEV) and generalized logistic (GLO) distributions were suitable. An additional goodness-of-fit measure was computed following the methods of Hosking and Wallis (1997) by considering the state as a single region. The goodness-of-fit Z statistics of the five candidate distributions are contained in Table 3. According to Hosking and Wallis (1997) if the absolute value of the Z-statistic is less than or equal to 1.64 then the hypothesis corresponding to acceptance of the candidate distribution is accepted at a confidence level of 90%. This test was formulated for a regional analysis and for this project the entire state was analyzed as a homogeneous region. To verify acceptability of this assumption, a heterogeneity measure (H statistic) was also computed following the procedures outlined in Hosking and Wallis (1997). The H statistics for all durations accompany the Z statistics in Table 3 and suggest the state is an acceptably homogeneous region for all durations except 15 and 30 minutes. The Z-statistics of the GLO distribution are less than those of the GEV distribution for 15 minutes and 30 minutes.

For all other durations the GEV distribution had the lowest Z-statistic. Thus, the GLO was selected for 15 and 30 minutes and the GEV was selected for all other durations. The selection of the GEV and GLO distribution is consistent with the majority of recent studies of extreme rainfall in the United States including studies in Texas, Oklahoma, Alabama, and Michigan.

Table 3. Summary of goodness-of-fit and heterogeneity measures for Arkansas (GPA = generalized Pareto, LN3 = log-normal (3 parameter), PE3 = Pearson Type 3).

Duration	Number of Stations	Goodness-of-fit Measure (Z-Statistic[1]) GEV	GLO	GPA	LN3	PE3	Heterogeneity Measure (H-statistic[1])
15 minute	79	-2.76	1.68	-11.85	-2.60	-3.28	3.53
30 minute	79	-3.59	0.98	-12.79	-3.27	-3.81	1.99
1 hour	129	-1.90	3.85	-14.21	-2.28	-3.82	1.01
2 hour	129	-1.19	4.15	-12.87	-1.84	-3.64	1.00
3 hour	129	-0.91	4.19	-12.29	-1.78	-3.83	1.02
6 hour	129	-1.10	3.94	-12.37	-1.99	-4.06	0.58
12 hour	129	-0.55	4.61	-12.06	-1.42	-3.47	0.75
1 day	334	0.27	11.1	-24.62	-2.43	-7.96	0.57
3 day	334	-1.93	9.55	-27.75	-5.58	-9.94	0.52
7 day	333	-3.98	-5.58	-31.81	-5.58	-9.94	0.31

[1]Hosking and Wallis (1997)

5.4 Parameter Estimation

Estimation of the parameters of a chosen probability distribution, on the basis of sample data values, can be accomplished in any of a number of different ways. The methods of moments and maximum likelihood are the classical ones, but more modern and more efficient methods involve the use of probability weighted moments (PWMs) (Greenwood et al. 1979) and *L*-moments (Hosking 1990; Hosking and Wallis 1997). *L*-moments, which are formed as linear combinations of order statistics, are less biased, less susceptible to the adverse effects of outliers, and have sampling distributions which are much more Gaussian than do conventional product moments.

For Arkansas rainfall, *L*-moments were employed for parameter estimation purposes. Following computation from the annual maxima series, the first *L*-moment (mean) for all durations at each site were corrected using the fixed-interval corrections presented by Weiss (1964). These corrections account for the systematic biases introduced into extracted annual rainfall maxima by fixed measurement times. To prevent the occurrence of increasing rainfall depths with increasing duration for chosen recurrence intervals, a simple correction was made to the *L*-CV and *L*-skewness. Following the approach taken in the development of the Alabama Rainfall Atlas (Durrans, personal communication), the *L*-CV and *L*-skewness were averaged over all durations at a given site. This was found to be reasonable based on inspection of the *L*-CV and *L*-skewness values computed for each site – there was only slight variability. For consistency this required the second *L*-moment for all durations at each site be adjusted to be the product of the corrected mean rainfall (based on Weiss correction factors) and the average *L*-CV.

The parameters of the GLO distribution were estimated from the corrected *L*-moments by the following (Hosking and Wallis 1997)

$$\kappa = -\tau_3 \tag{8}$$

$$\alpha = \frac{\lambda_2 \sin \kappa\pi}{\kappa\pi} \tag{9}$$

$$\xi = \lambda_1 - \alpha\left(\frac{1}{\kappa} - \frac{\pi}{\sin k\pi}\right) \tag{10}$$

The ξ parameter describes the location of the distribution. The α and κ parameters represent the scale and shape of the distribution.

The parameters of the GEV distribution were estimated from the corrected *L*-moments by the following (Hosking and Wallis 1997)

$$\kappa \approx 7.8590c + 2.9544c^2 \tag{11}$$

$$c = \frac{2}{3+\tau_3} - \frac{ln(2)}{ln(3)} \tag{12}$$

$$\alpha = \frac{\lambda_2 \kappa}{\left(1 - 2^{-k}\right)\Gamma(1+\kappa)} \tag{13}$$

$$\xi = \lambda_1 - \frac{\alpha}{\kappa}\left(1 - \Gamma(1+\kappa)\right) \tag{14}$$

As with the GLO distribution, the ξ parameter of the GEV distribution describes the location of the distribution, while the α and κ parameters represent the scale and shape of the distribution. For this project, both ξ and α have units of inches, while κ is dimensionless.

Parameter estimations for all sites and durations were performed independently of one another. That is, there was no pooling of data from statistically homogeneous sites in the sense of a regional analysis. Instead, regionalization is accomplished in the spatial smoothing approach employed in this study to permit estimation of rainfall characteristics at ungaged sites as described in the next section.

5.5 Spatial Smoothing and Quantile Estimates

Numerous approaches have been used to estimate extreme rainfall characteristics at ungaged locations. Spatial interpolation may be accomplished using geostatistical methods such as kriging (Asquith 1998) or a smoothing approach may be used that incorporates weighting of length of record and location (Durrans and Brown 1998). For this project, a spatial smoothing approach following from the technique used for studies of Oklahoma (Tortelli et al. 1999) and Alabama (Durrans, personal communication). The approach involved using the ArcGIS function POINTINTERP to develop raster surfaces from the point coverage of distribution parameters. The resulting surface is developed by assigning greater weighting to the closer sites. To include length of record in the weighting, the product of the parameter value and the length of record was found for each site and then the POINTINTERP function was used to derive the surface. A surface was also found for the length of record. The surface of the length of record weighted parameter was divided by the surface of the length of record to produce the final smoothed surface. This process was performed the three parameters of the GLO and GEV distributions. The resulting parameter raster databases are included in the accompanying CD and can be accessed by most GIS software packages. Raster calculator functions were used to derive the quantiles using the following equations (Hosking and Wallis 1997)

$$x(F) = \xi + \frac{\alpha}{\kappa}\left[1 - \left\{\frac{(1-F)}{F}\right\}^{\kappa}\right] \quad \text{for GLO} \tag{15}$$

$$x(F) = \xi + \frac{\alpha}{\kappa}\left[1 - \{-\ln(F)\}^{\kappa}\right] \quad \text{for GEV} \tag{16}$$

Using quantiles estimated for each 1-km by 1-km grid cell of the surface, contours are derived using the spatial analysis techniques. The resulting contour maps for each duration and return period combination are shown in a series of figures at the end of this report and in the accompanying map document.

5.6 Accuracy Assessment

The accuracy of the new products is difficult to assess because true frequency values are unknown. It can be assumed with great confidence that using more data and stronger statistical approaches will provide more accurate quantile estimates. The accuracy of the spatial smoothing technique can be assessed by computing the root mean square error (RMSE) of the surface value of the quantile at a location and the at-site estimate of the quantile at the same location. The computed RMSE was relatively small (Table 4a), which suggests the spatial smoothing approach effectively captures the at-site data and provides accurate estimates at ungaged sites. Although not very telling, simple comparisons between the revised estimates and the traditional TP-40 values were compiled for a small set of durations and return periods to show the new values compare reasonably to historical values, yet have higher precision and much greater spatial resolution (Table 4b). The final assessment of the products involved comparing the revised DDF estimates to estimates at the border obtained from revised DDF maps for

Oklahoma (Tortelli et al. 1999) and Texas (Asquith et al. 1998). The values for Arkansas were found to have only have a small discontinuity which should be negligible for most design applications.

Table 4a. Error measures of the quantile surface (contours) compared with the at-site values used to derive the surface.

Duration/ Frequency	Maximum Error (in.)	Minimum Error (in.)	RMSE (in.)	Bias (in.)
15 minute				
2 yr	-0.251	-0.001	0.101	-0.077
5 yr	-0.214	-0.001	0.094	-0.014
10 yr	0.268	-0.002	0.116	0.000
25 yr	-0.364	0.000	0.153	0.004
50 yr	-0.547	-0.003	0.189	0.001
100 yr	-0.788	-0.007	0.235	-0.006
500 yr	-1.629	0.004	0.391	-0.043
30 minute				
2 yr	-0.351	0.004	0.142	-0.105
5 yr	-0.292	0.000	0.131	-0.019
10 yr	0.370	-0.002	0.159	0.000
25 yr	-0.476	-0.001	0.208	0.006
50 yr	-0.725	0.004	0.255	0.002
100 yr	-1.053	-0.006	0.316	-0.008
500 yr	-2.197	0.014	0.526	-0.058
1 hour				
2 yr	-0.386	0.001	0.112	-0.007
5 yr	-0.586	0.005	0.170	-0.009
10 yr	-0.815	0.001	0.220	-0.013
25 yr	-1.171	-0.002	0.314	-0.025
50 yr	-1.487	-0.001	0.416	-0.042
100 yr	-1.852	0.001	0.551	-0.070
500 yr	-3.459	-0.002	1.027	-0.192
2 hour				
2 yr	-0.432	0.002	0.134	-0.002
5 yr	-0.727	-0.003	0.201	-0.001
10 yr	-1.012	0.001	0.260	-0.004
25 yr	-1.456	0.000	0.373	-0.016
50 yr	-1.852	-0.005	0.497	-0.037
100 yr	-2.306	-0.003	0.661	-0.069
500 yr	-4.231	0.010	1.243	-0.215

Table 4a (cont'd). Error measures of the quantile surface (contours) compared with the at-site values used to derive the surface.

Duration/ Frequency	Maximum Error (in.)	Minimum Error (in.)	RMSE (in.)	Bias (in.)
3 hour				
2 yr	-0.423	0.005	0.136	-0.003
5 yr	-0.784	0.002	0.203	-0.004
10 yr	-1.093	0.002	0.266	-0.007
25 yr	-1.578	0.004	0.393	-0.022
50 yr	-2.009	0.014	0.532	-0.044
100 yr	-2.505	-0.008	0.716	-0.082
500 yr	-4.854	0.008	1.364	-0.244
6 hour				
2 yr	-0.563	-0.004	0.174	-0.006
5 yr	-1.050	-0.003	0.259	-0.006
10 yr	-1.471	0.008	0.345	-0.011
25 yr	-2.129	-0.010	0.521	-0.031
50 yr	-2.716	0.017	0.715	-0.063
100 yr	-3.390	0.001	0.971	-0.114
500 yr	-6.330	-0.008	1.872	-0.339
12 hour				
2 yr	0.800	-0.007	0.185	-0.001
5 yr	1.199	-0.003	0.274	-0.001
10 yr	-1.512	-0.001	0.372	-0.005
25 yr	-2.219	0.010	0.577	-0.028
50 yr	-2.851	0.001	0.803	-0.064
100 yr	-3.581	0.007	1.100	-0.122
500 yr	-8.023	0.005	2.142	-0.378
1 day				
2 yr	1.171	0.001	0.242	-0.008
5 yr	1.728	0.001	0.326	-0.009
10 yr	2.143	-0.004	0.414	-0.019
25 yr	2.721	0.002	0.608	-0.051
50 yr	3.188	0.007	0.832	-0.096
100 yr	-4.264	-0.004	1.135	-0.162
500 yr	-10.897	0.009	2.218	-0.432

Table 4a (cont'd). Error measures of the quantile surface (contours) compared with the at-site values used to derive the surface.

Duration/ Frequency	Maximum Error (in.)	Minimum Error (in.)	RMSE (in.)	Bias (in.)
3 day				
2 yr	0.834	-0.002	0.249	-0.004
5 yr	1.374	0.001	0.339	-0.003
10 yr	1.792	-0.002	0.450	-0.014
25 yr	2.394	-0.001	0.705	-0.054
50 yr	-3.808	-0.006	1.001	-0.110
100 yr	-6.111	0.018	1.399	-0.193
500 yr	-15.032	0.019	2.808	-0.536
7 day				
2 yr	-1.150	-0.002	0.294	-0.024
5 yr	1.812	-0.004	0.395	-0.029
10 yr	2.328	0.001	0.519	-0.047
25 yr	3.061	0.003	0.812	-0.100
50 yr	-4.526	0.010	1.157	-0.169
100 yr	-7.270	-0.012	1.623	-0.271
500 yr	-17.892	-0.029	3.279	-0.684

Table 4b. Comparison of rainfall depths obtained from revised DDF and TP-40 (AHTD IDF curve based on TP-40) for selected return periods, durations, and locations.

Location	10-yr, 1-hr		100-yr, 1-hr		10-yr, 1-day		100-yr, 1-day	
	DDF	TP-40	DDF	TP-40	DDF	TP-40	DDF	TP-40
Fort Smith	2.40	2.70	3.20	3.80	6.00	6.40	8.25	9.00
Fayetteville	2.30	2.65	3.40	3.75	5.50	6.10	7.85	8.75
Little Rock	2.45	2.70	3.60	3.75	5.90	6.10	8.75	8.50
Paragould	2.70	2.40	4.00	3.40	5.50	5.50	7.85	7.50
Monticello	2.40	2.70	3.40	3.75	6.20	6.50	8.75	8.90

6. GIS PRODUCTS AND GRAPHICAL USER INTERFACE

The preceding sections of this report presented rainfall data collection and subsequent frequency analysis methods to produce the statistical distributions of the rainfall depths and intensity estimates. The accuracy and performance of the GLO and GEV distributions were studied and the spatial smoothing techniques used to generate the quantile estimates were presented. This section presents the development of the distribution parameters and quantile raster surfaces using these techniques coupled with GIS functionalities. The Graphic User Interface (GUI) developed to access these parameter raster surfaces for locations within Arkansas and calculate the subsequent IDF or DDF tables or graphs is also presented.

6.1 GIS Products

The POINTINTERP function in ArcGIS was used to generate spatially smoothed parameter rasters using the point shapefiles as mentioned in the previous section. This function restricts the interpolation of output raster cells to consider only the points (raingage locations) in a specified neighborhood. In other words, the influence of a certain rain gage location's rainfall depth/intensity on the interpolated grid cell value depends on its distance from the interpolated cell. The three parameter rasters generated are 1) location factor ξ 2) scale parameter α and 3) shape parameter κ of the rain gage population. Figures 4, 5, and 6 present raster surfaces containing the interpolated location, scale and shape factors for the 15-min duration, as an example. The spatial distribution of the parameters is similar for other durations.

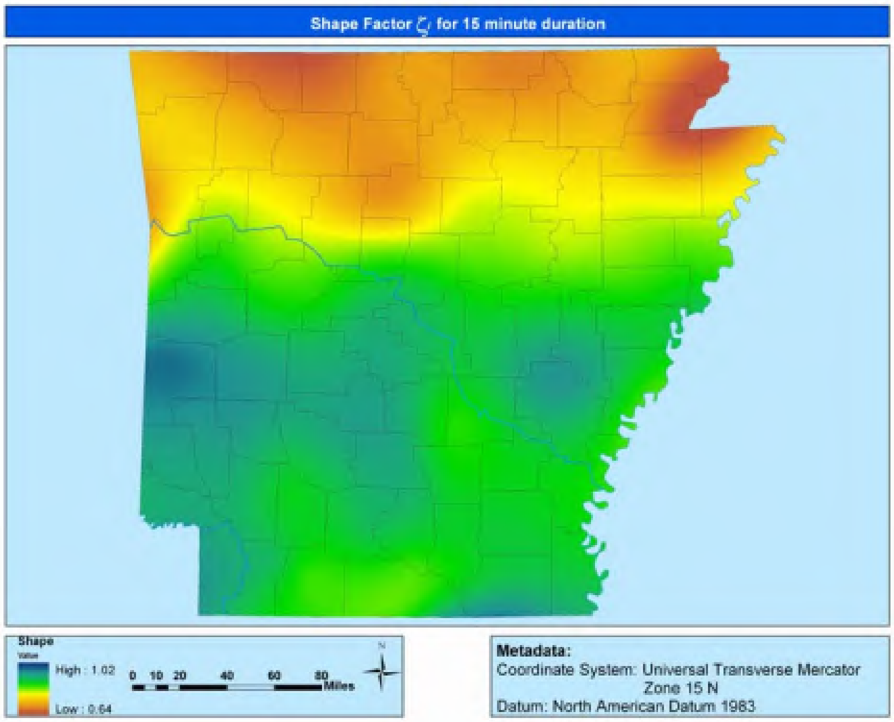


Figure 4. Raster surface of location factor.

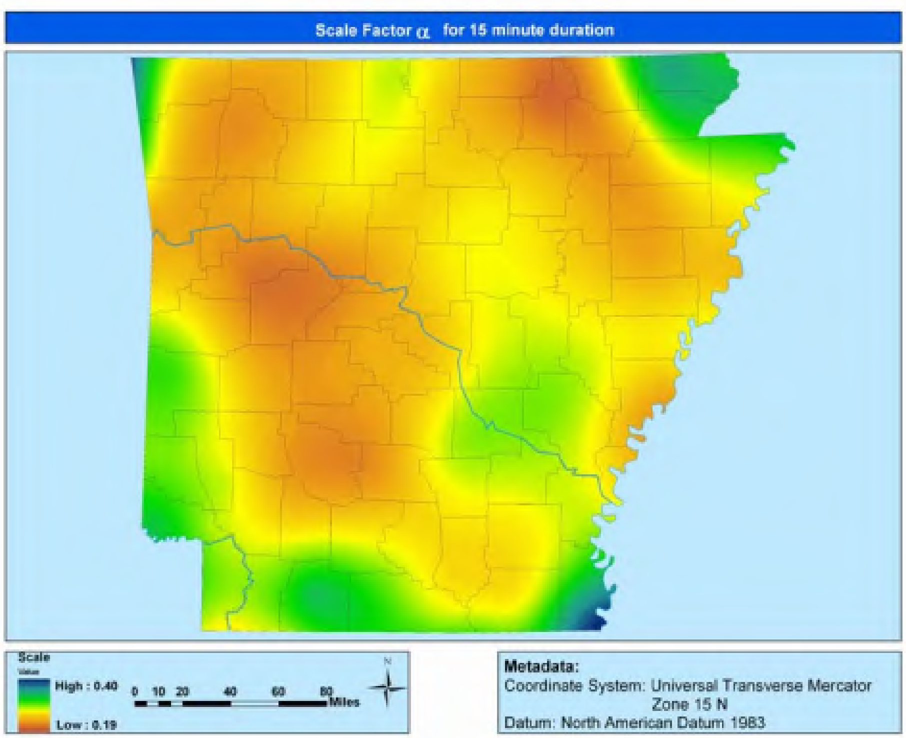


Figure 5. Raster surface of scale factor.

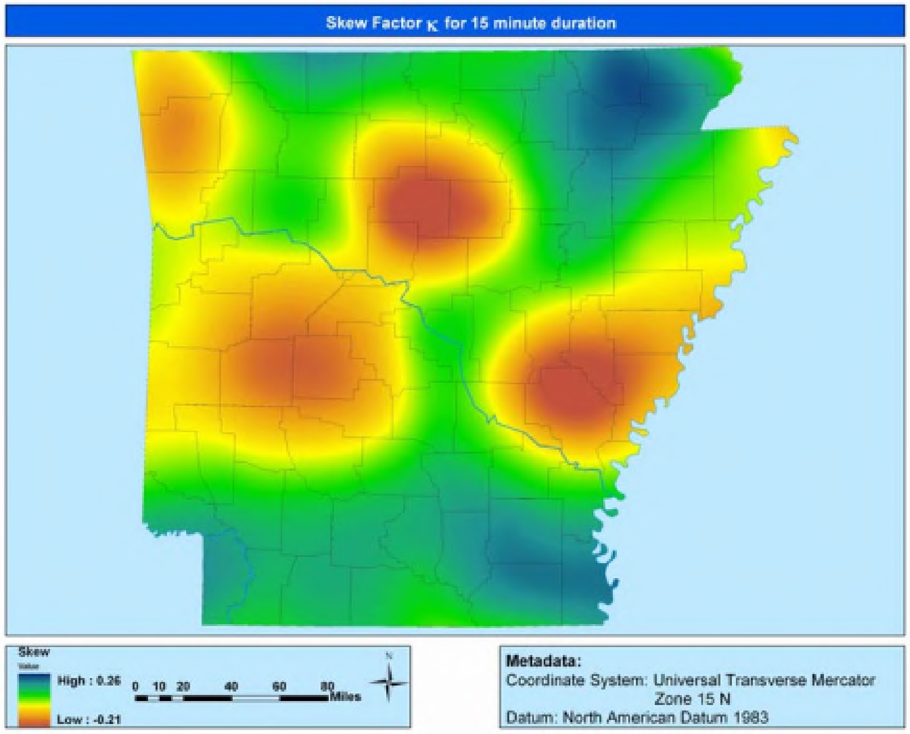


Figure 6. Raster surface of shape factor.

Observing Figures 4 to 6, one notes the presence of low values in the north-central region of the state. This and the north-south trend observed can be linked to the topography of the state. The Boston Mountains divide the state into two sections, blocking the moisture from the Gulf coast and creating two different precipitation zones. The shape parameter surface does not vary significantly over the durations included in the analysis. This is because the surface is generated using an aggregate value of all durations at a location. These parameter rasters are used by the graphical user interface to derive user-specified IDF and DDF values as described in the next section.

6.2 Graphical User Interface

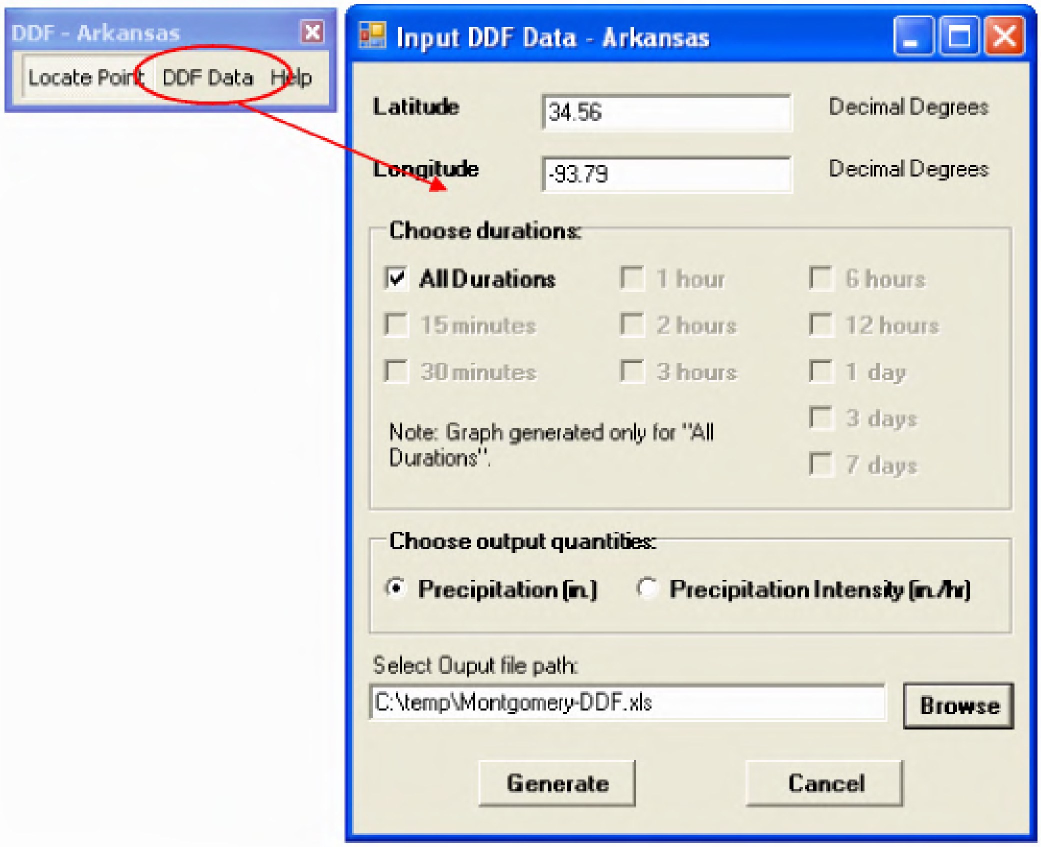
The graphical user interface (GUI) developed for this project (a toolbar in ArcGIS) contains a set of simple functions to 1) locate the user's point of interest (POI) by clicking on a map of Arkansas or manually entering the location latitude and longitude coordinates, and 2) generate the output IDF or DDF table for return periods ranging from 2 yrs to 500 yrs and durations ranging from 15 min to 7 days, in Microsoft® Excel file format. DDF or IDF curves can also be generated if all the durations are selected. The functions of the GUI are illustrated in the following step-by-step description and then example.

1. On the CD accompanying the report there are three folders. One folder (**Data**) contains the data (distribution parameter rasters and shapefiles of boundary and counties or Arkansas) and the second (**Setup**) is the toolbar setup. A third folder (**Quantile Rasters**) contains the quantile raster files that can be accessed by users if they wish (the quantile rasters are not used by the tool because it uses distribution parameter rasters to generate the quantiles). **Warning: Do not rename any of the folders or files associated with the tool because the tool code is hardwired to work with the specific file names. Do not change the folder structure. Also do not modify any of the distribution parameter rasters in the Data folder, unless the databases are being updated in future DDF revisions.**
2. Copy the **Data** and **Setup** folders to the local hard drive. **The system requirements for the tool are ArcGIS 9.1 (either ArcView or ArcInfo level), Microsoft Excel 2003, and Windows XP Service Pack 2 (must have .NET framework updated to 2.0 in XP).**
3. In the **Setup** folder double click on **Setup.exe**. This will open the install wizard for the Arkansas **DDF Tool**. Follow the install wizard steps to install the tool.
4. After installation, navigate to the **Data** folder and double click the ArcMap document containing the tool (**Arkansas-DDF-Calculator.mxd**). An ArcMap documenting displaying the counties of Arkansas is opened. **Warning: Do not modify any of the file names or datasets shown in the project table of contents – they are hardwired for use with the tool and changes to the table of contents will make the tool inoperable.**
5. If the toolbar is not present, the user must add the toolbar to the ArcMap interface. This is accomplished by navigating under the **Tools** menu to **Customize…** and under the **Toolbars** tab clicking **DDF – Arkansas**. It is

recommended that ArcMap document be saved so the toolbar does not need to be added in the future.

6. The basic functions of the tool are shown below in the toolbar that appears: **Locate Point**, **DDF Data**, and **Help**. By clicking on **Locate Point**, the user activates a point-and-click function permitting the user to select the POI in the **State of Arkansas boundary (the user must select a point within the boundary for the tool to work properly)**. Once the POI is selected the user must click **DDF Data** on the toolbar (the most recent point clicked on the map will be the point registered in the tool; thus, if a point is inadvertently selected simply click again in the correct location to reset). Note: double clicking in the map when the point-and-click function is active will deactivate the **Locate Point** function.

7. By clicking **DDF Data** in the toolbar after selecting the POI a user form opens allowing the user to enter the output details. The user form is shown below. Alternatively, the user can click on this button first (before **Locate Point**) to manually input the latitude and longitude coordinates of the POI in the user form.
8. The durations for which the DDF or IDF values are to be calculated are selected by checking the appropriate boxes. Durations shown range from 15 minutes to 7 days. **All Durations** may also be checked. Output DDF or IDF curves are generated by default if **All Durations** is selected.



9. The radio button **Precipitation** can be selected for generating output in DDF (depth-duration-frequency) form and **Precipitation Intensity** for IDF (intensity-duration-frequency) form (default is DDF).
10. The output file path must be designated using the standard Windows Browse capability. Remember the output file path you select so you can locate the output results.
11. Click the **Generate** button after specifying the inputs and outputs. The **Cancel** button may be clicked to close the form and return to the ArcMap document. The tool generates the DDF or IDF tables (and curves) in the Excel file (.xls) at the user specified location.

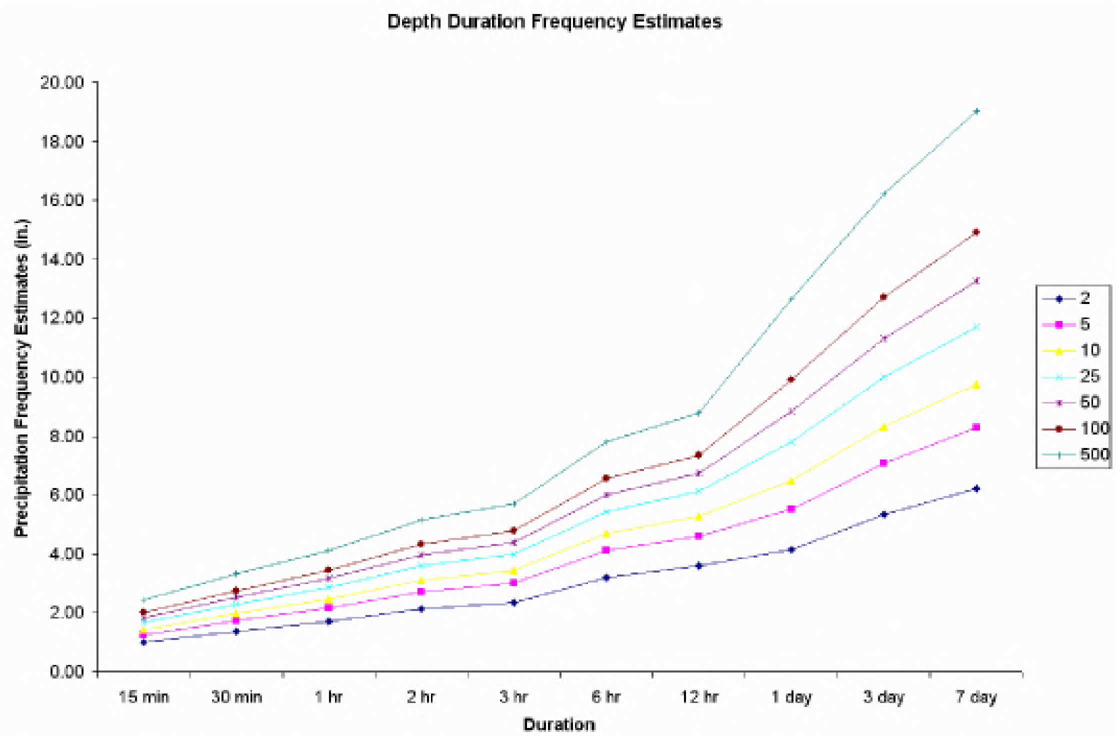
A brief example is provided to lead you through the steps and permit you to check output. The POI for the test case is latitude 34.56 and longitude -93.79 (note the negative for

West), a point in Montgomery County (west central Arkansas). You can either attempt to locate the point using the point-and-click function (click on **Locate Point)** or simply click on **DDF Data** and enter the coordinates in the user form as shown in the user form above. Set the output file path as shown above and select **All Durations**. The output table and the plot are shown on the following page. Your results should be similar.

Note: When the Excel output file is closed memory used in the random access memory (RAM) may not be freed depending on system configurations. Therefore, if the tool is executed multiple times without closing, the memory may not automatically be cleared. If this problem arises the memory can be manually cleared by navigating to **Task Manager** and under "Processes", select "Excel.exe" and click "End Process" button. Or simply restart the computer after generating numerous outputs with the tool if the problem arises.

ARI (years)	Precipitation Frequency Estimates (in.)									
	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	1 day	3 day	7 day
2	1.00	1.36	1.70	2.13	2.35	3.21	3.61	4.15	5.32	6.23
5	1.26	1.72	2.17	2.72	3.01	4.11	4.62	5.52	7.07	8.28
10	1.44	1.97	2.48	3.11	3.44	4.70	5.28	6.49	8.32	9.74
25	1.67	2.28	2.87	3.60	3.98	5.44	6.12	7.80	10.00	11.71
50	1.84	2.52	3.16	3.97	4.39	5.99	6.74	8.83	11.32	13.27
100	2.01	2.76	3.45	4.33	4.79	6.54	7.35	9.91	12.71	14.90
500	2.43	3.32	4.12	5.17	5.71	7.81	8.77	12.65	16.22	19.02

Note:
ARI = Average Recurrence Interval


Depth Duration Frequency Estimates
Precipitation Frequency Estimates (in.)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
15 min
30 min
1 hr
2 hr
3 hr
6 hr
12 hr
1 day
3 day
7 day
Duration
2
5
10
25
50
100
500

7. SUMMARY

This report describes the effort to update the rainfall depth-duration-frequency (DDF) data for the State of Arkansas. DDF data have been the basis for local stormwater drainage design, sizing of culverts, and design of bridges and waterways, and more. Improvement in the DDF data will improve the safety and cost-effectiveness of the designs. For this reason, the Arkansas Highway and Transportation Department (AHTD) chose to update the DDF data used for their hydrologic and hydraulic design projects.

For this project, the best available data from rain gages recording at 15-minute, hourly, and daily time increments were obtained from Hydrosphere and Earthinfo, two third party vendors of rainfall data collected and archived by the National Oceanic and Atmospheric Administration (NOAA). Annual maxima for 79 15-minute gages, 129 hourly gages, and 334 daily rain gages were determined for 15-minute, 30-minute, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour, 1-day, 3-day, and 7-day durations.

The annual maxima series were analyzed to compute the *L*-moments and *L*-moment ratios for each site and for all durations. The *L*-moments and *L*-moment ratios computed were the mean, *L*-scale, *L*-coefficient of variation (*L*-CV), *L*-skewness, and *L*-kurtosis. The generalized logistic (GLO) distribution was selected to model the 15-minute and 30-minutes annual maxima and the generalized extreme value (GEV) distribution was selected to model the other durations. The *L*-moments and *L*-moment ratios were corrected to account for fixed-interval sampling and to maintain monotonically increasing depths for increasing return periods and durations. The distribution parameters were computed at each site for all durations using the corrected *L*-moments and *L*-moment ratios.

To estimate DDF data at ungaged locations a spatial smoothing approach was implemented. Using geospatial technologies the distance from nearby stations and length of record were used to derived a weighted surface of parameter values for all durations. These derived parameter surfaces are used to compute quantile surfaces. The parameter databases are included in the CD accompanying this report along with a graphical user interface (GUI) for simple access. The quantile surfaces are used to derive contour maps of quantile values that are included at the end of this report and in the accompanying map document.

8. REFERENCES

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Table 5. Daily precipitation stations used in frequency analysis.

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
1	9203	VINITA 2 N	OK	36°32'49"	95°07'56"	56
2	8380	SPAVINAW	OK	36°23'22"	95°03'35"	56
3	3700	GRAND RIVER DAM	OK	36°28'00"	95°03'00"	32
4	3182	FLASHMAN TOWER	OK	34°29'00"	95°00'00"	35
5	5693	MC CURTAIN 1 SE	OK	35°08'41"	94°58'01"	56
6	8677	TAHLEQUAH	OK	35°56'13"	94°57'52"	56
7	584	BEAR MOUNTAIN TOWER	OK	34°08'22"	94°57'07"	50
8	567	BATTIEST	OK	34°23'06"	94°53'53"	70
9	3065	FANSHAWE	OK	34°57'13"	94°53'52"	56
10	5855	MIAMI	OK	36°53'00"	94°53'00"	54
11	991	BOXELDER 3 NNE	TX	33°30'59"	94°51'39"	54
12	4451	IDABEL	OK	33°52'53"	94°49'10"	56
13	4820	KIAMICHI TOWER	OK	34°38'00"	94°49'00"	22
14	7862	SALLISAW 2 NW	OK	35°27'26"	94°48'17"	56
15	4564	JAY	OK	36°25'00"	94°48'00"	49
16	1544	CARTER TOWER	OK	34°15'58"	94°46'31"	56
17	4672	KANSAS 2 NE	OK	36°12'48"	94°46'21"	45
18	3794	GROVE	OK	36°34'50"	94°46'05"	28
19	1162	BROKEN BOW 1 N	OK	34°02'57"	94°44'19"	56
20	5437	LYONS 2 N	OK	35°45'46"	94°44'04"	56
21	9773	WYANDOTTE 1 N	OK	36°49'00"	94°43'00"	21
22	9724	WISTER 3 S	OK	34°56'30"	94°42'14"	33
23	1168	BROKEN BOW DAM	OK	34°08'00"	94°42'00"	34
24	6190	NAPLES 1 SW	TX	33°11'00"	94°41'00"	89
25	4017	HEE MOUNTAIN TOWER	OK	34°20'00"	94°39'00"	47
26	8506	STILWELL 5 NNW	OK	35°53'43"	94°38'55"	56
27	2352	DEKALB	TX	33°38'05"	94°38'17"	55
28	1499	CARNASAW TOWER	OK	34°08'39"	94°38'16"	54
29	7246	POTEAU	OK	35°03'00"	94°38'00"	55
30	9985	ZOE 1 S	OK	34°45'00"	94°38'00"	37
31	8416	SPIRO	OK	35°14'42"	94°37'30"	56
32	7656	SENECA 1 W	MO	36°50'00"	94°37'17"	20
33	8285	SMITHVILLE	OK	34°28'59"	94°36'46"	56
34	4008	HEAVENER 2 N	OK	34°54'46"	94°35'59"	52
35	8335	SIMMS 4 WNW	TX	33°22'00"	94°34'00"	15
36	6624	SILOAM SPRINGS	AR	36°10'00"	94°32'00"	40
37	2930	GRAVETTE	AR	36°25'34"	94°26'53"	56
38	164	ANDERSON	MO	36°39'07"	94°26'19"	56
39	1666	COVE	AR	34°25'53"	94°25'03"	56
40	5354	ODELL 2 N	AR	35°46'49"	94°24'58"	56
41	6270	NEW BOSTON	TX	33°27'17"	94°24'32"	24
42	2544	FOREMAN	AR	33°42'59"	94°22'53"	26
43	5160	NATURAL DAM	AR	35°34'32"	94°22'52"	41
44	5229	LINDEN	TX	33°00'58"	94°22'03"	55
45	2574	FORT SMITH REGIONAL AP	AR	35°19'59"	94°21'45"	104

Table 5 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
46	5976	NEOSHO	MO	36°51'50"	94°21'36"	86
47	3442	HORATIO	AR	33°56'06"	94°21'31"	56
48	1948	DEQUEEN	AR	34°02'47"	94°20'53"	56
49	5667	MAUD	TX	33°19'59"	94°20'35"	58
50	4577	JEFFERSON	TX	32°46'14"	94°20'05"	92
51	2908	GRANNIS	AR	34°15'00"	94°20'00"	28
52	4116	LEE CREEK GUARD STATION	AR	35°42'00"	94°19'00"	15
53	1172	CAMP CHAFFEE	AR	35°18'00"	94°18'00"	12
54	2976	GREENWOOD	AR	35°13'01"	94°15'35"	56
55	4756	MENA	AR	34°34'23"	94°14'58"	62
56	586	BENTONVILLE 4 S	AR	36°19'19"	94°12'54"	56
57	6	ABBOTT	AR	35°04'35"	94°12'09"	56
58	7488	WALDRON	AR	34°53'57"	94°11'39"	55
59	2444	FAYETTEVILLE EXP STN	AR	36°06'02"	94°10'28"	112
60	2442	FAYETTEVILLE	AR	36°05'00"	94°10'00"	13
61	2443	FAYETTEVILLE FAA AIRPOR	AR	36°00'00"	94°10'00"	34
62	8944	TEXARKANA DAM	TX	33°18'00"	94°10'00"	49
63	408	ATLANTA	TX	33°07'28"	94°09'58"	59
64	2578	FORT SMITH WATER PLANT	AR	35°39'00"	94°09'00"	56
65	6248	ROGERS	AR	36°22'00"	94°06'00"	28
66	286	ASHDOWN 4 SSE	AR	33°37'09"	94°05'59"	52
67	8942	TEXARKANA	TX	33°26'05"	94°04'03"	36
68	7812	WHITE CLIFFS	AR	33°48'00"	94°04'00"	14
69	3584	INDEX	AR	33°35'00"	94°03'00"	22
70	2015	DIERKS	AR	34°07'36"	94°01'02"	44
71	5072	MULBERRY 6 NNE	AR	35°34'00"	94°01'00"	37
72	7048	TEXARKANA WEBB FIELD	AR	33°27'13"	94°00'27"	67
73	7950	RODESSA	LA	32°58'00"	94°00'00"	56
74	300	ATHENS	AR	34°19'19"	93°58'32"	54
75	6364	MOORINGSPORT 1 N	LA	32°42'18"	93°57'39"	29
76	664	BIG FORK 1 SSE	AR	34°28'09"	93°57'24"	56
77	7772	WHITE ROCK	AR	35°41'00"	93°57'00"	22
78	7645	SELIGMAN	MO	36°32'31"	93°56'12"	79
79	5700	MONETT	MO	36°55'00"	93°56'00"	55
80	830	BOONEVILLE 3 SSE	AR	35°09'00"	93°55'00"	56
81	5376	OKAY	AR	33°46'00"	93°55'00"	45
82	5760	PINE RIDGE	AR	34°35'00"	93°54'04"	56
83	1520	COLD SPRINGS GUARD STN	AR	34°58'00"	93°54'00"	11
84	2556	FORESTER 4 WNW	AR	34°47'00"	93°53'00"	56
85	6008	RATCLIFF	AR	35°18'18"	93°52'36"	56
86	4398	HOSSTON	LA	32°53'12"	93°52'24"	56
87	5158	NATHAN 4 WNW	AR	34°07'00"	93°52'00"	56
88	1383	CASSVILLE RANGER STN	MO	36°40'22"	93°51'28"	59
89	5112	NASHVILLE	AR	33°55'49"	93°51'05"	56
90	5174	NEWHOPE 3 E	AR	34°14'00"	93°50'00"	36
91	5508	OZARK	AR	35°29'00"	93°49'00"	74

Table 5 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
92	4060	LANGLEY	AR	34°15'53"	93°48'55"	55
93	2670	FULTON	AR	33°36'46"	93°48'49"	38
94	1574	COMBS 3 SE	AR	35°48'00"	93°48'00"	20
95	2356	EUREKA SPRINGS 3 WNW	AR	36°24'59"	93°47'30"	56
96	3537	HAILEY 3 WSW	MO	36°42'00"	93°46'00"	22
97	518	BEAVER 1 SE	AR	36°28'00"	93°46'00"	12
98	5358	ODEN 1 SE	AR	34°36'03"	93°46'00"	56
99	3540	HUNTSVILLE	AR	36°05'00"	93°44'00"	44
100	1814	DAISY	AR	34°15'00"	93°44'00"	27
101	5576	PARIS	AR	35°18'00"	93°43'00"	24
102	5110	NARROWS DAM	AR	34°08'43"	93°42'50"	21
103	5079	MURFREESBORO 1 W	AR	34°04'42"	93°42'07"	33
104	7344	PLAIN DEALING	LA	32°54'18"	93°41'56"	71
105	5010	MOUNT MAGAZINE	AR	35°10'00"	93°41'00"	19
106	2922	GRAVELLY 1 ESE	AR	34°52'33"	93°40'34"	56
107	3438	HOPPER 1 E	AR	34°21'37"	93°40'10"	56
108	798	BLUE MOUNTAIN DAM	AR	35°06'58"	93°39'02"	41
109	6928	SUBIACO	AR	35°18'10"	93°38'13"	56
110	616	BERRYVILLE 5 NW	AR	36°25'46"	93°37'32"	53
111	4988	MOUNT IDA 3 SE	AR	34°32'27"	93°35'16"	56
112	4185	LEWISVILLE	AR	33°21'41"	93°34'04"	52
113	3428	HOPE 3 NE	AR	33°42'32"	93°33'22"	94
114	2842	GLENWOOD	AR	34°19'44"	93°32'06"	56
115	6890	STORY	AR	34°42'00"	93°31'00"	45
116	920	BODCAU FIRE TOWER	LA	32°42'00"	93°31'00"	30
117	1010	BUFFALO TOWER	AR	35°52'00"	93°30'00"	40
118	136	ALY	AR	34°48'00"	93°28'00"	35
119	3094	GALENA	MO	36°48'15"	93°27'58"	56
120	7038	TAYLOR	AR	33°05'55"	93°27'53"	53
121	150	AMITY 1 N	AR	34°16'51"	93°27'41"	53
122	2121	COTTON VALLEY 5 NNW	LA	32°53'13"	93°27'25"	56
123	1455	CLARKSVILLE	AR	35°29'00"	93°27'00"	55
124	8683	SPRINGHILL	LA	32°59'32"	93°26'31"	36
125	4727	LAMPE FOREST SERVICE	MO	36°34'00"	93°26'00"	13
126	2946	GREEN FOREST	AR	36°20'21"	93°25'40"	47
127	820	BONNERDALE 4 SW	AR	34°22'00"	93°25'23"	39
128	178	ANTOINE	AR	34°02'09"	93°25'18"	56
129	5514	OZONE	AR	35°38'42"	93°25'09"	49
130	1982	DEVILS KNOB	AR	35°43'00"	93°24'00"	22
131	1834	DANVILLE	AR	35°02'19"	93°23'40"	56
132	5908	PRESCOTT	AR	33°47'51"	93°22'36"	74
133	848	BOUGHTON	AR	33°52'00"	93°20'00"	35
134	6856	STEVE	AR	34°53'00"	93°19'00"	12
135	6244	MINDEN	LA	32°36'19"	93°17'41"	56
136	4548	MAGNOLIA	AR	33°15'02"	93°14'01"	56
137	5770	PINEY GROVE	AR	34°10'22"	93°12'18"	37

Table 5 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
138	1900	DEER	AR	35°49'38"	93°12'16"	29
139	764	BLAKELY MOUNTAIN DAM	AR	34°34'11"	93°11'41"	53
140	3600	JASPER	AR	36°00'02"	93°11'18"	56
141	1838	DARDANELLE	AR	35°14'03"	93°10'03"	53
142	800	BLUFF CITY 3 SW	AR	33°41'31"	93°09'52"	56
143	5200	NIMROD DAM	AR	34°57'19"	93°09'34"	56
144	3165	HARRISON BOONE CNTY AP	AR	36°16'00"	93°09'24"	43
145	724	BISMARCK 2 SE	AR	34°17'14"	93°08'40"	39
146	5428	OMAHA 4 NE	AR	36°29'19"	93°08'02"	16
147	3074	GURDON	AR	33°55'00"	93°08'00"	39
148	4131	HAYNESVILLE	LA	32°58'08"	93°07'48"	37
149	6460	OZARK BEACH	MO	36°39'35"	93°07'34"	55
150	3164	HARRISON	AR	36°13'25"	93°07'19"	49
151	7262	TURNPIKE	AR	35°40'00"	93°05'00"	13
152	4355	HOMER 3 SSW	LA	32°45'02"	93°04'03"	54
153	4386	LURTON 2 NE	AR	35°48'00"	93°04'00"	27
154	220	ARKADELPHIA 2 N	AR	34°08'36"	93°03'32"	74
155	3704	JESSIEVILLE	AR	34°42'04"	93°03'26"	56
156	3466	HOT SPRINGS 1 NNE	AR	34°30'52"	93°03'08"	56
157	1238	CARPENTER DAM	AR	34°27'00"	93°01'00"	15
158	3235	HECTOR 2 SSW	AR	35°26'00"	93°00'00"	41
159	188	APLIN 1 W	AR	34°58'00"	93°00'00"	28
160	253	ANTIOCH FIRE TOWER	LA	32°53'00"	93°00'00"	29
161	4106	LEAD HILL	AR	36°25'16"	92°54'34"	56
162	6102	REMMEL DAM	AR	34°26'00"	92°54'00"	15
163	130	ALUM FORK	AR	34°47'46"	92°50'30"	56
164	4562	MALVERN	AR	34°22'54"	92°49'42"	56
165	6768	SPARKMAN	AR	33°54'55"	92°49'36"	56
166	1152	CAMDEN 1	AR	33°35'24"	92°49'25"	74
167	2300	EL DORADO GOODWIN FLD	AR	33°13'15"	92°48'51"	74
168	5691	PERRY	AR	35°02'52"	92°47'59"	56
169	5498	OWENSVILLE	AR	34°36'48"	92°46'27"	55
170	4938	MORRILTON	AR	35°09'29"	92°46'02"	83
171	2794	GILBERT	AR	35°59'29"	92°42'53"	73
172	8084	YELLVILLE 2 SSE	AR	36°12'00"	92°40'00"	41
173	4666	MARSHALL	AR	35°54'56"	92°38'22"	55
174	582	BENTON	AR	34°34'03"	92°36'02"	56
175	4134	LEOLA	AR	34°10'27"	92°35'41"	56
176	1020	BULL SHOALS DAM	AR	36°21'53"	92°34'41"	14
177	8754	WASOLA	MO	36°47'32"	92°34'16"	56
178	8669	SPEARSVILLE FIRE TOWER	LA	32°54'00"	92°34'00"	50
179	4010	LAKE MAUMELLE	AR	34°51'04"	92°29'20"	45
180	1140	CALION LOCK & DAM	AR	33°18'17"	92°29'06"	56
181	842	BOTKINBURG 3 NE	AR	35°43'12"	92°28'15"	13
182	1492	CLINTON	AR	35°34'44"	92°27'50"	56
183	1750	CRYSTAL VALLEY	AR	34°41'19"	92°27'00"	56

Table 5 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
184	2540	FORDYCE	AR	33°49'22"	92°25'56"	67
185	1596	CONWAY	AR	35°05'03"	92°25'44"	112
186	3079	FARMERVILLE	LA	32°46'30"	92°24'27"	38
187	5036	MOUNTAIN HOME 1 NNW	AR	36°20'45"	92°23'38"	91
188	6562	SHERIDAN	AR	34°18'07"	92°23'29"	27
189	5038	MOUNTAIN HOME C OF ENG	AR	36°20'00"	92°23'00"	35
190	1829	DAMASCUS 2 NNE	AR	35°24'17"	92°23'00"	51
191	2962	GREENBRIER	AR	35°14'07"	92°21'43"	52
192	6566	SHERIDAN TOWER	AR	34°27'00"	92°21'00"	30
193	6586	SHIRLEY	AR	35°39'00"	92°19'00"	41
194	4250	LITTLE ROCK FILT PLANT	AR	34°46'00"	92°19'00"	28
195	3087	FARMERVILLE 6 E	LA	32°47'00"	92°17'00"	11
196	3258	HENDERSON 2 W	AR	36°22'00"	92°16'00"	13
197	5320	N LITTLE ROCK WFO AP	AR	34°50'07"	92°15'35"	28
198	8313	TECUMSEH	MO	36°35'19"	92°15'24"	56
199	4248	LITTLE ROCK ADAMS FLD	AR	34°43'38"	92°14'20"	107
200	2302	DORA	MO	36°46'47"	92°13'58"	45
201	6174	RISON	AR	33°57'14"	92°12'07"	15
202	5908	MARION 7 SE	LA	32°49'00"	92°10'00"	42
203	1132	CALICO ROCK 2 WSW	AR	36°06'33"	92°09'49"	74
204	2519	ELIJAH	MO	36°36'00"	92°09'00"	14
205	2475	FELSENTHAL L & D	AR	33°03'35"	92°07'25"	20
206	5046	MOUNTAIN VIEW	AR	35°54'53"	92°06'15"	56
207	7582	WARREN 2 WSW	AR	33°36'16"	92°05'59"	55
208	8785	STERLINGTON	LA	32°42'11"	92°04'54"	56
209	7780	SILOAM SPRINGS	MO	36°48'52"	92°04'10"	56
210	5754	PINE BLUFF	AR	34°13'32"	92°01'08"	116
211	3862	KEO	AR	34°36'19"	92°00'26"	56
212	1102	CABOT 4 SW	AR	34°58'54"	92°00'23"	56
213	537	BASTROP	LA	32°46'08"	92°00'20"	56
214	2978	GREERS FERRY DAM	AR	35°31'14"	91°59'59"	50
215	8795	STEVENSON FIRE TOWER	LA	32°54'00"	91°58'00"	23
216	1730	CROSSETT 2 SSE	AR	33°06'40"	91°56'57"	56
217	4746	MELBOURNE	AR	36°04'24"	91°56'45"	56
218	5756	PINE BLUFF FAA AIRPORT	AR	34°10'00"	91°56'00"	27
219	6820	STAR CITY 2 S	AR	33°54'00"	91°51'00"	47
220	8880	WEST PLAINS	MO	36°44'33"	91°50'05"	56
221	4900	MONTICELLO 3 SW	AR	33°35'50"	91°48'40"	56
222	6403	SALEM	AR	36°21'22"	91°48'13"	49
223	458	BATESVILLE LIVESTOCK	AR	35°49'50"	91°47'40"	62
224	3088	HAMBURG	AR	33°13'40"	91°47'38"	48
225	6868	OAK RIDGE	LA	32°37'33"	91°46'23"	35
226	1191	CANE CREEK STATE PARK	AR	33°54'55"	91°46'16"	47
227	1224	CARLISLE 1 SW	AR	34°47'00"	91°45'00"	28
228	6506	SEARCY	AR	35°16'06"	91°42'59"	74
229	4625	KOSHKONONG	MO	36°36'00"	91°39'00"	43

Table 5 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
230	460	BATESVILLE L&D 1	AR	35°45'36"	91°38'20"	56
231	2366	EVENING SHADE 1 NNE	AR	36°04'52"	91°36'51"	56
232	1768	CUMMINS FARM	AR	34°04'00"	91°35'00"	18
233	350	BALD KNOB	AR	35°18'00"	91°34'00"	19
234	2971	EPPS 6 WNW	LA	32°37'00"	91°34'00"	30
235	6918	STUTTGART	AR	34°29'52"	91°33'28"	74
236	4572	MAMMOTH SPRING	AR	36°29'41"	91°32'06"	56
237	2148	DUMAS	AR	33°53'05"	91°31'54"	74
238	5866	PORTLAND	AR	33°14'17"	91°30'16"	92
239	1968	DES ARC	AR	34°58'38"	91°29'52"	56
240	872	BRADFORD	AR	35°25'00"	91°28'00"	13
241	2760	GEORGETOWN	AR	35°07'40"	91°26'56"	56
242	1960	DERMOTT	AR	33°31'00"	91°26'00"	56
243	6920	STUTTGART 9 ESE	AR	34°28'28"	91°25'02"	89
244	6866	OAK GROVE 2 WSW	LA	32°51'47"	91°23'21"	34
245	326	AUGUSTA 2 NW	AR	35°18'20"	91°23'16"	56
246	7524	WALNUT GROVE 2 NNE	AR	35°51'00"	91°21'00"	14
247	240	ARKANSAS POST	AR	34°01'30"	91°20'40"	41
248	3831	KELSO 3 NW	AR	33°49'04"	91°20'23"	19
249	4708	MCARTHUR	AR	33°41'12"	91°20'01"	19
250	127	ALTON 6 SE	MO	36°37'48"	91°18'16"	47
251	1442	CLARENDON	AR	34°41'34"	91°17'54"	51
252	5186	NEWPORT	AR	35°36'15"	91°16'28"	74
253	6253	ROHWER 2 NNE	AR	33°48'36"	91°16'13"	45
254	234	ARKANSAS CITY	AR	33°36'42"	91°11'59"	56
255	936	BRINKLEY	AR	34°52'57"	91°11'16"	56
256	5090	LAKE PROVIDENCE	LA	32°48'23"	91°10'22"	73
257	2355	EUDORA	AR	33°04'07"	91°09'28"	42
258	3611	GREENVILLE 8 SW	MS	33°18'00"	91°08'00"	29
259	6376	SAINT CHARLES	AR	34°22'36"	91°07'38"	56
260	746	BLACK ROCK	AR	36°06'24"	91°06'14"	56
261	7886	SCOTT	MS	33°36'00"	91°05'00"	31
262	3605	GREENVILLE	MS	33°21'33"	91°03'36"	84
263	64	ALICIA 2 NNE	AR	35°55'44"	91°03'30"	56
264	536	BEEDEVILLE 4 NE	AR	35°27'30"	91°03'22"	56
265	7582	ROSEDALE	MS	33°51'00"	91°01'00"	35
266	5820	POCAHONTAS 1	AR	36°15'50"	90°58'05"	56
267	6562	ONWARD	MS	32°43'30"	90°56'24"	39
268	7530	WALNUT RIDGE FAA AIRPOR	AR	36°08'00"	90°56'00"	21
269	4678	MARVELL	AR	34°33'00"	90°55'00"	12
270	8445	STONEVILLE EXP STN	MS	33°25'52"	90°54'39"	84
271	7560	ROLLING FORK	MS	32°53'52"	90°53'07"	56
272	6351	NITTA YUMA	MS	33°02'00"	90°51'00"	32
273	2289	DONIPHAN	MO	36°37'14"	90°48'45"	56
274	2564	FORREST CITY	AR	35°02'00"	90°48'00"	21
275	8052	WYNNE	AR	35°15'17"	90°47'47"	56

Table 5 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
276	4638	MARIANNA 2 S	AR	34°44'01"	90°45'58"	93
277	2563	ELLSINORE	MO	36°56'00"	90°45'00"	25
278	4528	MADISON 1 NW	AR	35°01'35"	90°44'05"	56
279	1738	CLEVELAND	MS	33°44'00"	90°44'00"	74
280	512	BEATY LAKE	AR	35°05'00"	90°43'00"	13
281	4155	HOLLY BLUFF	MS	32°49'00"	90°43'00"	25
282	3734	JONESBORO 2 NE	AR	35°50'55"	90°41'17"	109
283	534	BEECH GROVE	AR	36°11'00"	90°38'00"	28
284	3242	HELENA	AR	34°31'16"	90°35'25"	56
285	1632	CORNING	AR	36°25'11"	90°35'09"	74
286	5586	PARKIN 2 W	AR	35°16'00"	90°35'00"	16
287	1707	CLARKSDALE	MS	34°11'11"	90°33'26"	74
288	5562	PARAGOULD	AR	36°01'58"	90°29'29"	56
289	3998	LAKE CITY	AR	35°48'00"	90°27'00"	48
290	4654	MARKED TREE	AR	35°32'00"	90°25'00"	44
291	6791	POPLAR BLUFF	MO	36°45'28"	90°24'20"	86
292	8996	TUNICA	MS	34°41'00"	90°23'00"	56
293	9154	VANCE 1 SW	MS	34°04'00"	90°22'00"	37
294	4869	LAMBERT 1 W	MS	34°12'06"	90°18'21"	56
295	8700	WAPPAPELLO DAM	MO	36°55'23"	90°17'01"	56
296	6970	QULIN	MO	36°35'01"	90°13'31"	56
297	8145	SLEDGE	MS	34°26'14"	90°12'55"	56
298	4842	LAKE CORMORANT	MS	34°54'16"	90°12'43"	56
299	2881	FISK	MO	36°46'58"	90°12'12"	50
300	7807	SARAH 3 SE	MS	34°32'00"	90°11'00"	56
301	7712	WEST MEMPHIS	AR	35°07'27"	90°10'50"	42
302	6934	PUXICO 1 SE	MO	36°56'00"	90°09'00"	43
303	6380	SAINT FRANCIS	AR	36°27'07"	90°08'49"	55
304	237	ARKABUTLA DAM	MS	34°44'59"	90°08'01"	56
305	676	BIG LAKE OUTLET	AR	35°51'00"	90°08'00"	13
306	3999	HORNERSVILLE	MO	36°02'37"	90°06'41"	15
307	3821	KEISER	AR	35°41'14"	90°05'47"	45
308	4417	KENNETT RADIO KBOA	MO	36°13'31"	90°04'30"	51
309	1221	CAMPBELL	MO	36°29'00"	90°04'00"	26
310	5964	MEMPHIS POST OFFICE BLD	TN	35°09'00"	90°03'00"	38
311	5954	MEMPHIS INTL AP	TN	35°03'23"	89°59'11"	64
312	3975	HERNANDO	MS	34°48'58"	89°59'07"	73
313	5205	MALDEN FAA AIRPORT	MO	36°36'00"	89°59'00"	56
314	5480	OSCEOLA	AR	35°43'00"	89°59'00"	28
315	595	BERNIE	MO	36°40'18"	89°58'18"	56
316	2235	DEXTER	MO	36°48'00"	89°58'00"	39
317	7921	SENATOBIA	MS	34°37'53"	89°57'33"	56
318	1052	BURDETTE	AR	35°49'00"	89°57'00"	28
319	735	BLOOMFIELD	MO	36°53'27"	89°55'51"	56
320	7066	PLEASANT HILL	MS	34°53'56"	89°54'43"	56
321	806	BLYTHEVILLE	AR	35°55'26"	89°54'16"	74

Table 5 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
322	4377	INDEPENDENCE 1 W	MS	34°41'56"	89°49'17"	47
323	6532	PARMA	MO	36°36'45"	89°48'58"	51
324	5956	MEMPHIS WFO	TN	35°07'47"	89°48'13"	17
325	884	BOLTON	TN	35°19'00"	89°45'00"	42
326	2108	COVINGTON 3 SW	TN	35°32'59"	89°42'00"	76
327	6799	PORTAGEVILLE	MO	36°26'00"	89°41'00"	51
328	1262	BYHALIA	MS	34°52'00"	89°41'00"	47
329	1364	CARUTHERSVILLE	MO	36°10'07"	89°39'51"	86
330	7710	RIPLEY	TN	35°44'44"	89°31'44"	42
331	9020	TIPTONVILLE	TN	36°23'00"	89°29'00"	15
332	2685	DYERSBURG III GOLF	TN	36°00'01"	89°24'36"	56
333	6471	NEWBERN	TN	36°07'00"	89°16'00"	46
334	1145	BROWNSVILLE	TN	35°35'22"	89°15'31"	74

Table 6. Hourly precipitation stations used in frequency analysis.

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
1	3700	GRAND RIVER DAM	OK	36°28'00"	95°03'00"	19
2	7732	ROSE	OK	36°13'00"	95°02'00"	32
3	1773	CLARKSVILLE 1 W	TX	33°36'36"	95°01'18"	48
4	7675	ROBERT S KERR DAM	OK	35°20'57"	94°46'42"	12
5	1544	CARTER TOWER	OK	34°15'58"	94°46'31"	44
6	1168	BROKEN BOW DAM	OK	34°08'00"	94°42'00"	26
7	9719	WISTER 3 NE	OK	35°00'00"	94°41'00"	18
8	4010	HEAVENER EXPERIMENT FAR	OK	34°55'00"	94°36'00"	18
9	8335	SIMMS 4 WNW	TX	33°22'00"	94°34'00"	26
10	6270	NEW BOSTON	TX	33°27'17"	94°24'32"	23
11	2544	FOREMAN	AR	33°42'59"	94°22'53"	29
12	1952	DE QUEEN DAM	AR	34°06'01"	94°22'21"	21
13	2574	FORT SMITH REGIONAL AP	AR	35°19'59"	94°21'45"	55
14	4577	JEFFERSON	TX	32°46'14"	94°20'05"	27
15	4756	MENA	AR	34°34'23"	94°14'58"	46
16	2810	GILLHAM DAM	AR	34°12'20"	94°14'47"	27
17	7488	WALDRON	AR	34°53'57"	94°11'39"	46
18	7694	WEST FORK	AR	35°55'00"	94°11'00"	15
19	2444	FAYETTEVILLE EXP STN	AR	36°06'02"	94°10'28"	26
20	8944	TEXARKANA DAM	TX	33°18'00"	94°10'00"	39
21	2020	DIERKS DAM	AR	34°08'51"	94°05'20"	18
22	8942	TEXARKANA	TX	33°26'05"	94°04'03"	21
23	6016	RAVANA	AR	33°04'00"	94°02'00"	19
24	7048	TEXARKANA WEBB FIELD	AR	33°27'13"	94°00'27"	25
25	887	BRANCH 4 NW	AR	35°21'00"	94°00'00"	12
26	4839	MILLWOOD DAM	AR	33°40'38"	93°59'25"	29
27	888	BRANCH 3 SW	AR	35°16'00"	93°59'00"	12
28	825	BOONEVILLE 6 NW	AR	35°12'00"	93°59'00"	11
29	6007	RATCLIFF 5 NNW	AR	35°22'00"	93°55'00"	12
30	830	BOONEVILLE 3 SSE	AR	35°09'00"	93°55'00"	27
31	832	BOONEVILLE 3 SSE	AR	35°06'17"	93°54'32"	15
32	827	BOONEVILLE 6 NNE	AR	35°13'00"	93°54'00"	12
33	6005	RATCLIFF 2 S	AR	35°17'00"	93°53'00"	12
34	5114	NASHVILLE	AR	33°57'00"	93°52'00"	11
35	1383	CASSVILLE RANGER STN	MO	36°40'22"	93°51'28"	35
36	5112	NASHVILLE	AR	33°55'49"	93°51'05"	32
37	826	BOONEVILLE 7 NE	AR	35°13'00"	93°50'00"	12
38	6006	RATCLIFF 5 NE	AR	35°21'00"	93°49'00"	12
39	1574	COMBS 3 SE	AR	35°48'00"	93°48'00"	26
40	5577	PARIS 4 WSW	AR	35°16'00"	93°48'00"	12
41	2356	EUREKA SPRINGS 3 WNW	AR	36°24'59"	93°47'30"	50
42	3544	HUNTSVILLE 1 SSW	AR	36°04'12"	93°45'08"	11
43	3540	HUNTSVILLE	AR	36°05'00"	93°44'00"	32
44	1814	DAISY	AR	34°15'00"	93°44'00"	26
45	5110	NARROWS DAM	AR	34°08'43"	93°42'50"	34
46	7344	PLAIN DEALING	LA	32°54'18"	93°41'56"	11
47	798	BLUE MOUNTAIN DAM	AR	35°06'58"	93°39'02"	49
48	616	BERRYVILLE 5 NW	AR	36°25'46"	93°37'32"	50

Table 6 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
49	4988	MOUNT IDA 3 SE	AR	34°32'27"	93°35'16"	40
50	4185	LEWISVILLE	AR	33°21'41"	93°34'04"	28
51	3428	HOPE 3 NE	AR	33°42'32"	93°33'22"	13
52	7950	WING	AR	34°57'00"	93°28'00"	31
53	136	ALY	AR	34°48'00"	93°28'00"	26
54	178	ANTOINE	AR	34°02'09"	93°25'18"	36
55	1457	CLARKSVILLE 6 NE	AR	35°31'58"	93°24'13"	25
56	1834	DANVILLE	AR	35°02'19"	93°23'40"	40
57	5910	PRESCOTT SCS	AR	33°48'00"	93°23'00"	32
58	5908	PRESCOTT	AR	33°47'51"	93°22'36"	15
59	1582	COMPTON	AR	36°05'31"	93°18'29"	45
60	8252	TABLE ROCK DAM	MO	36°35'50"	93°18'27"	19
61	6244	MINDEN	LA	32°36'19"	93°17'41"	36
62	5602	PARTHENON	AR	35°57'14"	93°14'31"	41
63	4550	MAGNOLIA 2	AR	33°16'00"	93°14'00"	23
64	764	BLAKELY MOUNTAIN DAM	AR	34°34'11"	93°11'41"	28
65	5200	NIMROD DAM	AR	34°57'19"	93°09'34"	43
66	2975	FORSYTH	MO	36°42'00"	93°07'00"	37
67	220	ARKADELPHIA 2 N	AR	34°08'36"	93°03'32"	50
68	1238	CARPENTER DAM	AR	34°27'00"	93°01'00"	14
69	3235	HECTOR 2 SSW	AR	35°26'00"	93°00'00"	13
70	6102	REMMEL DAM	AR	34°26'00"	92°54'00"	14
71	196	APPLETON	AR	35°25'00"	92°53'00"	18
72	5970	PYATT	AR	36°15'00"	92°51'00"	15
73	1154	CAMDEN 2	AR	33°35'00"	92°51'00"	17
74	130	ALUM FORK	AR	34°47'46"	92°50'30"	39
75	1152	CAMDEN 1	AR	33°35'24"	92°49'25"	21
76	2794	GILBERT	AR	35°59'29"	92°42'53"	46
77	8084	YELLVILLE 2 SSE	AR	36°12'00"	92°40'00"	14
78	761	BERNICE 2 S	LA	32°47'00"	92°40'00"	15
79	4696	MAUMEE	AR	36°03'00"	92°39'00"	26
80	1020	BULL SHOALS DAM	AR	36°21'53"	92°34'41"	42
81	8754	WASOLA	MO	36°47'32"	92°34'16"	28
82	8669	SPEARSVILLE FIRE TOWER	LA	32°54'00"	92°34'00"	14
83	1140	CALION LOCK & DAM	AR	33°18'17"	92°29'06"	11
84	842	BOTKINBURG 3 NE	AR	35°43'12"	92°28'15"	38
85	2489	FERNDALE 6 E	AR	34°45'34"	92°27'19"	11
86	4934	MOROBAY LOCK	AR	33°19'00"	92°27'00"	33
87	5036	MOUNTAIN HOME 1 NNW	AR	36°20'45"	92°23'38"	36
88	3904	KINGSLAND 3 SSE	AR	33°50'00"	92°16'00"	18
89	5320	N LITTLE ROCK WFO AP	AR	34°50'07"	92°15'35"	28
90	5228	NORFORK DAM	AR	36°14'58"	92°15'22"	43
91	4248	LITTLE ROCK ADAMS FLD	AR	34°43'38"	92°14'20"	31
92	2302	DORA	MO	36°46'47"	92°13'58"	26
93	3556	HUTTIG LOCK	AR	33°02'00"	92°05'00"	24
94	3230	HEBER SPRINGS 3 SSW	AR	35°28'00"	92°03'00"	15
95	5754	PINE BLUFF	AR	34°13'32"	92°01'08"	37
96	2978	GREERS FERRY DAM	AR	35°31'14"	91°59'59"	27

Table 6 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
97	7744	WHEELING 3 W	AR	36°19'00"	91°54'00"	30
98	530	BEEBE	AR	35°03'52"	91°53'46"	29
99	8880	WEST PLAINS	MO	36°44'33"	91°50'05"	36
100	4900	MONTICELLO 3 SW	AR	33°35'50"	91°48'40"	29
101	458	BATESVILLE LIVESTOCK	AR	35°49'50"	91°47'40"	41
102	460	BATESVILLE L&D 1	AR	35°45'36"	91°38'20"	38
103	2971	EPPS 6 WNW	LA	32°37'00"	91°34'00"	18
104	2148	DUMAS	AR	33°53'05"	91°31'54"	30
105	3132	HARDY	AR	36°16'29"	91°30'20"	24
106	4906	MONTROSE	AR	33°19'00"	91°29'00"	17
107	2297	DARNELL 2N	LA	32°42'00"	91°27'00"	18
108	6920	STUTTGART 9 ESE	AR	34°28'28"	91°25'02"	46
109	326	AUGUSTA 2 NW	AR	35°18'20"	91°23'16"	32
110	127	ALTON 6 SE	MO	36°37'48"	91°18'16"	26
111	936	BRINKLEY	AR	34°52'57"	91°11'16"	37
112	64	ALICIA 2 NNE	AR	35°55'44"	91°03'30"	32
113	7560	ROLLING FORK	MS	32°53'52"	90°53'07"	31
114	2564	FORREST CITY	AR	35°02'00"	90°48'00"	27
115	8052	WYNNE	AR	35°15'17"	90°47'47"	13
116	4638	MARIANNA 2 S	AR	34°44'01"	90°45'58"	23
117	1743	CLEVELAND 3 N	MS	33°47'39"	90°42'46"	34
118	1632	CORNING	AR	36°25'11"	90°35'09"	27
119	1707	CLARKSDALE	MS	34°11'11"	90°33'26"	25
120	8700	WAPPAPELLO DAM	MO	36°55'23"	90°17'01"	34
121	237	ARKABUTLA DAM	MS	34°44'59"	90°08'01"	40
122	5946	MEMPHIS SEWAGE PLANT	TN	35°12'00"	90°02'00"	27
123	5954	MEMPHIS INTL AP	TN	35°03'23"	89°59'11"	50
124	5205	MALDEN FAA AIRPORT	MO	36°36'00"	89°59'00"	30
125	6358	MUNFORD	TN	35°27'20"	89°48'41"	17
126	1262	BYHALIA	MS	34°52'00"	89°41'00"	35
127	5720	MASON	TN	35°24'56"	89°31'53"	36
128	2680	DYERSBURG	TN	36°02'44"	89°22'11"	36
129	1150	BROWNSVILLE SEWER PLANT	TN	35°35'05"	89°16'09"	35

Table 7. 15-minute precipitation stations used in frequency analysis.

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
1	7739	ROSE TOWER	OK	36°10'00"	95°01'00"	25
2	1773	CLARKSVILLE 1 W	TX	33°36'00"	95°01'00"	18
3	7675	ROBERT S KERR DAM	OK	35°20'00"	94°47'00"	29
4	1544	CARTER TOWER	OK	34°15'00"	94°46'00"	28
5	6270	NEW BOSTON	TX	33°27'00"	94°24'00"	26
6	1952	DE QUEEN DAM	AR	34°06'00"	94°22'00"	15
7	2544	FOREMAN	AR	33°42'00"	94°22'00"	15
8	4756	MENA	AR	34°34'23"	94°14'58"	15
9	2810	GILLHAM DAM	AR	34°12'00"	94°14'00"	27
10	7488	WALDRON	AR	34°53'57"	94°11'39"	24
11	2444	FAYETTEVILLE EXP STN	AR	36°06'02"	94°10'28"	28
12	2020	DIERKS DAM	AR	34°08'00"	94°05'00"	15
13	4839	MILLWOOD DAM	AR	33°40'00"	93°59'00"	15
14	832	BOONEVILLE 3 SSE	AR	35°06'17"	93°54'32"	20
15	5112	NASHVILLE	AR	33°55'49"	93°51'05"	24
16	1383	CASSVILLE RANGER STN	MO	36°40'00"	93°51'00"	16
17	2356	EUREKA SPRINGS 3 WNW	AR	36°24'59"	93°47'30"	15
18	6393	ST PAUL	AR	35°49'25"	93°46'02"	11
19	3544	HUNTSVILLE 1 SSW	AR	36°04'12"	93°45'08"	16
20	5110	NARROWS DAM	AR	34°08'43"	93°42'50"	28
21	798	BLUE MOUNTAIN DAM	AR	35°06'58"	93°39'02"	15
22	616	BERRYVILLE 5 NW	AR	36°25'46"	93°37'32"	15
23	4988	MOUNT IDA 3 SE	AR	34°32'27"	93°35'16"	28
24	900	BRIGGSVILLE	AR	34°56'00"	93°29'00"	15
25	6804	STAMPS	AR	33°22'00"	93°29'00"	19
26	8683	SPRINGHILL	LA	32°59'00"	93°26'00"	13
27	178	ANTOINE	AR	34°02'09"	93°25'18"	15
28	1457	CLARKSVILLE 6 NE	AR	35°31'58"	93°24'13"	21
29	5908	PRESCOTT	AR	33°47'51"	93°22'36"	15
30	8252	TABLE ROCK DAM	MO	36°35'00"	93°18'00"	29
31	1582	COMPTON	AR	36°05'00"	93°18'00"	16
32	6244	MINDEN	LA	32°36'00"	93°17'00"	29
33	5602	PARTHENON	AR	35°57'00"	93°15'00"	15
34	4548	MAGNOLIA	AR	33°15'02"	93°14'01"	22
35	764	BLAKELY MOUNTAIN DAM	AR	34°34'11"	93°11'41"	28
36	5200	NIMROD DAM	AR	34°57'19"	93°09'34"	15
37	6460	OZARK BEACH	MO	36°39'00"	93°07'00"	17
38	220	ARKADELPHIA 2 N	AR	34°08'36"	93°03'32"	27
39	130	ALUM FORK	AR	34°47'46"	92°50'30"	28
40	1152	CAMDEN 1	AR	33°35'24"	92°49'25"	27
41	2794	GILBERT	AR	35°59'29"	92°42'53"	15
42	1020	BULLS SHOALS DAM	AR	36°22'00"	92°34'00"	28
43	1140	CALION LOCK & DAM	AR	33°18'17"	92°29'06"	14
44	842	BOTKINBURG 3 NE	AR	35°43'00"	92°28'00"	15
45	2489	FERNDALE 6 E	AR	34°46'00"	92°27'00"	18
46	5228	NORFORK DAM	AR	36°15'00"	92°15'00"	28

Table 7 (cont'd)

SITE NO.	STATION ID	STATION NAME	STATE	LATITUDE	LONGITUDE	MODIFIED YEARS OF RECORD
47	2302	DORA	MO	36°46'00"	92°13'00"	17
48	6314	MONROE NLU	LA	32°32'00"	92°04'00"	23
49	5754	PINE BLUFF	AR	34°13'32"	92°01'08"	25
50	2978	GREERS FERRY DAM	AR	35°31'14"	91°59'59"	27
51	530	BEEBE	AR	35°03'00"	91°53'00"	28
52	8880	WEST PLAINS	MO	36°44'00"	91°50'00"	17
53	4900	MONTICELLO 3 SW	AR	33°35'50"	91°48'40"	28
54	6403	SALEM	AR	36°21'22"	91°48'13"	12
55	458	BATESVILLE LIVESTOCK	AR	35°49'50"	91°47'40"	15
56	460	BATESVILLE L&D 1	AR	35°45'09"	91°37'52"	14
57	2971	EPPS 6 WNW	LA	32°37'00"	91°34'00"	17
58	2148	DUMAS	AR	33°53'05"	91°31'54"	28
59	3132	HARDY	AR	36°16'00"	91°30'00"	15
60	6920	STUTTGART 9 ESE	AR	34°28'28"	91°25'02"	28
61	326	AUGUSTA 2 NW	AR	35°18'20"	91°23'16"	23
62	936	BRINKLEY	AR	34°52'57"	91°11'16"	28
63	64	ALICIA	AR	35°53'39"	91°04'57"	16
64	8445	STONEVILLE EXP STN	MS	33°26'00"	90°55'00"	23
65	7560	ROLLING FORK	MS	32°53'00"	90°53'00"	21
66	8052	WYNNE	AR	35°15'17"	90°47'47"	20
67	1743	CLEVELAND 3 N	MS	33°48'00"	90°43'00"	28
68	1632	CORNING	AR	36°25'11"	90°35'09"	16
69	1707	CLARKSDALE	MS	34°12'00"	90°34'00"	29
70	8700	WAPPAPELLO DAM	MO	36°55'00"	90°17'00"	29
71	237	ARKABUTLA DAM	MS	34°44'00"	90°08'00"	19
72	3999	HORNERSVILLE	MO	36°03'00"	90°07'00"	16
73	5946	MEMPHIS	TN	35°12'00"	90°02'00"	14
74	2608	DRUMMONS	TN	35°28'00"	89°55'00"	29
75	6358	MUNFORD	TN	35°27'00"	89°48'00"	18
76	1262	BYHALIA	MS	34°52'00"	89°41'00"	19
77	5720	MASON	TN	35°24'00"	89°32'00"	28
78	2680	DYERSBURG	TN	36°02'00"	89°23'00"	25
79	1150	BROWNSVILLE SEWAGE PLAN	TN	35°35'00"	89°16'00"	29

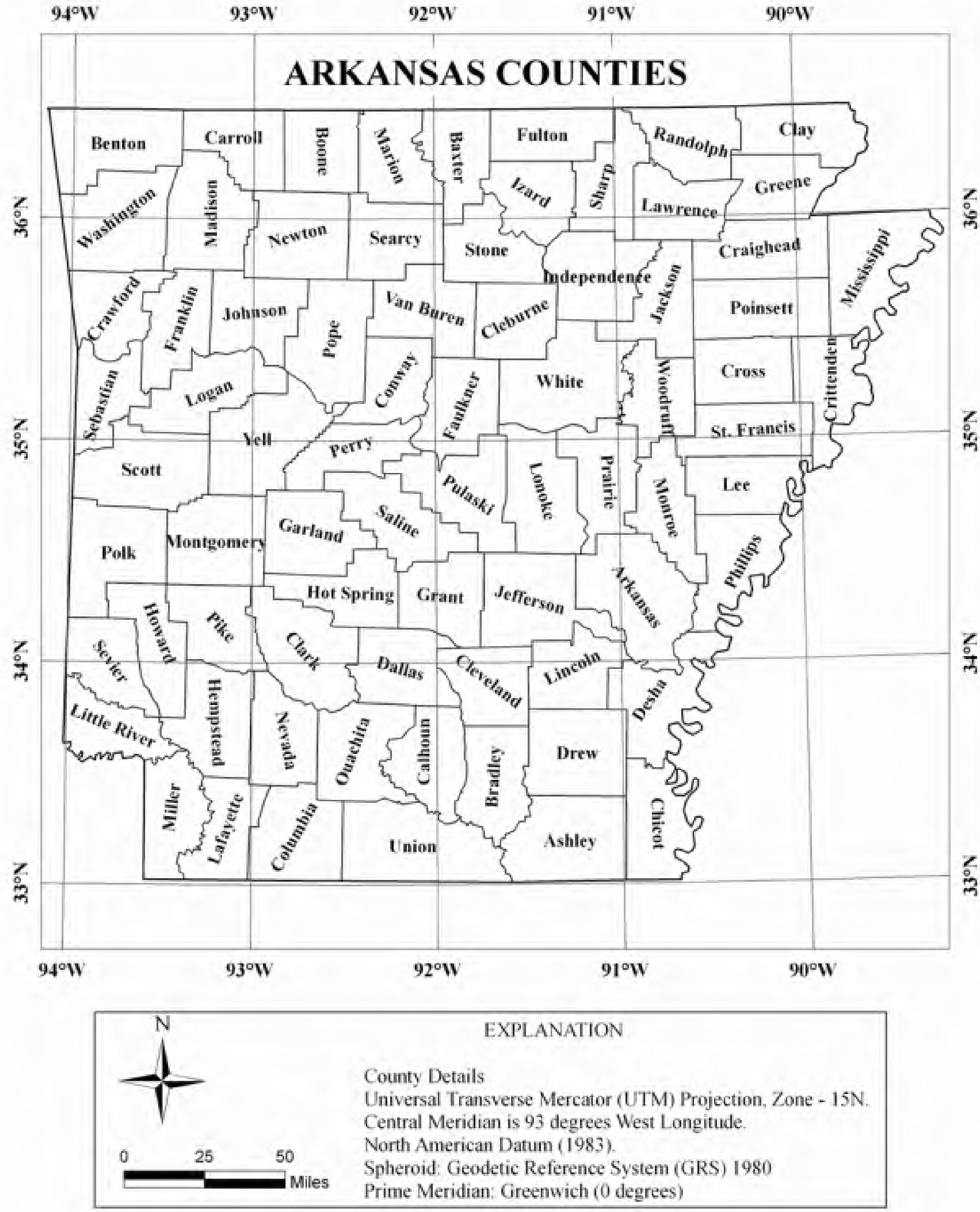

Figure 7. Arkansas county boundary map – corresponds to base data layer in rainfall depth contour maps on the following pages.

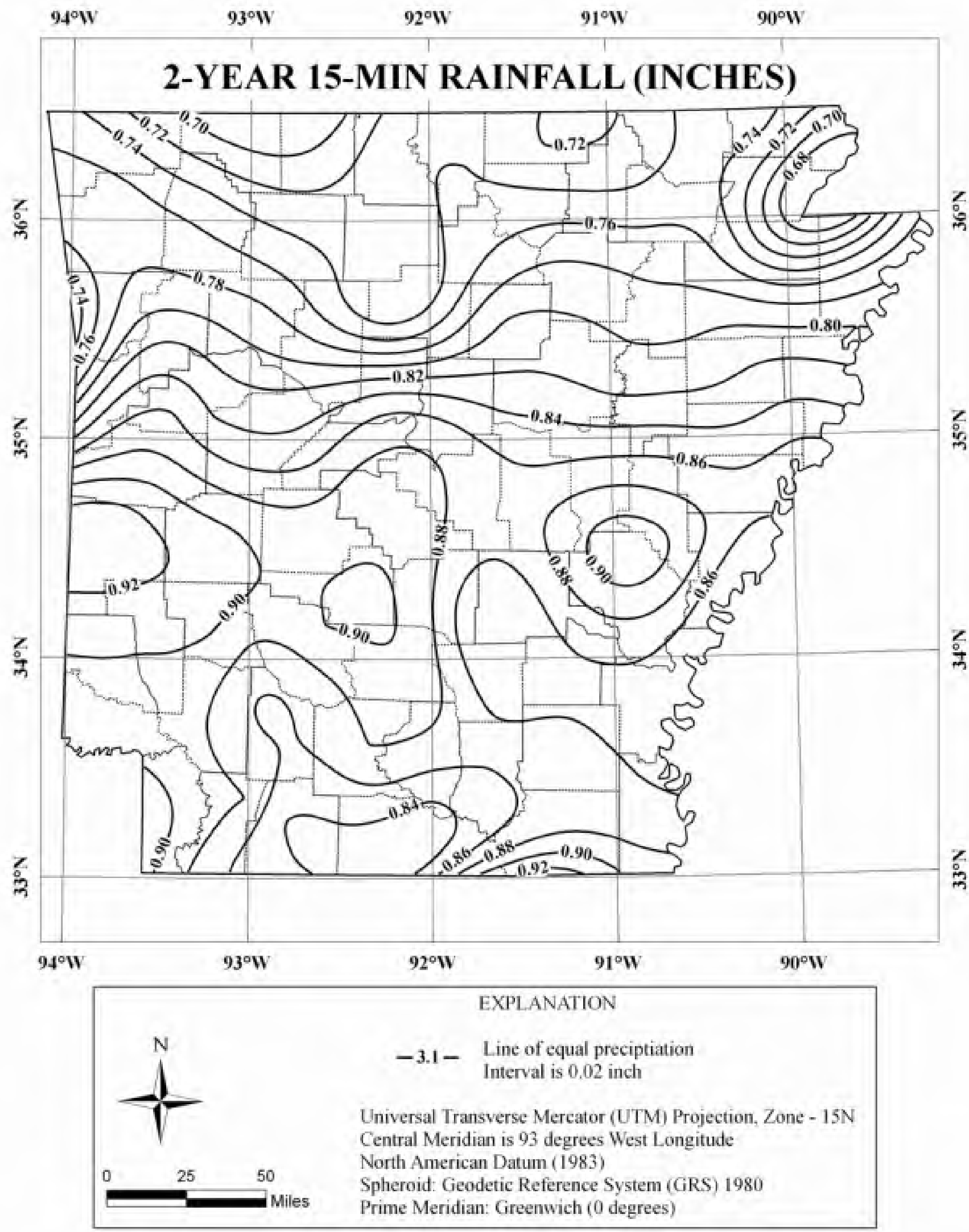

Figure 8. Depth of 2-year storm for 15-minute interval in Arkansas.

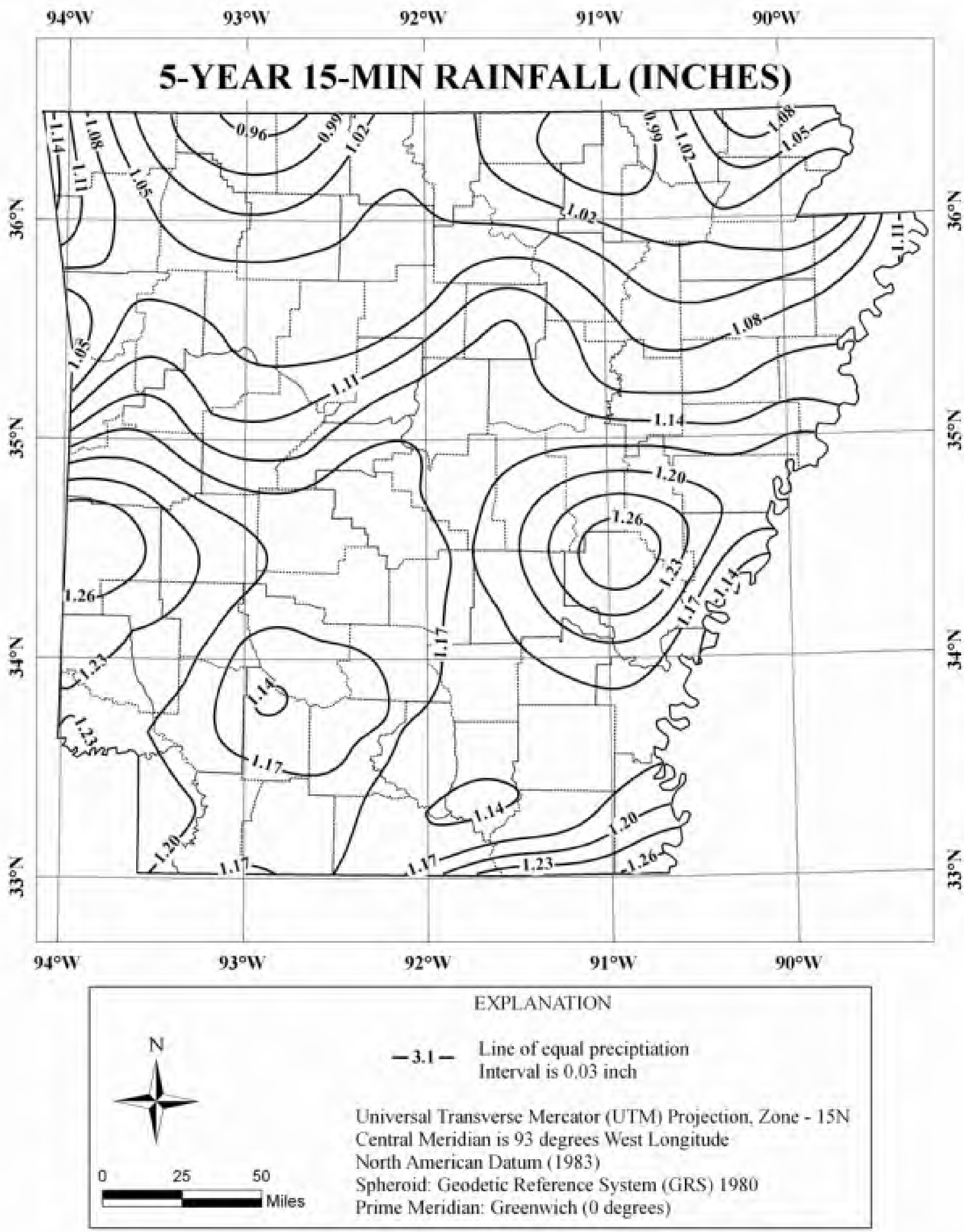

Figure 9. Depth of 5-year storm for 15-minute interval in Arkansas.

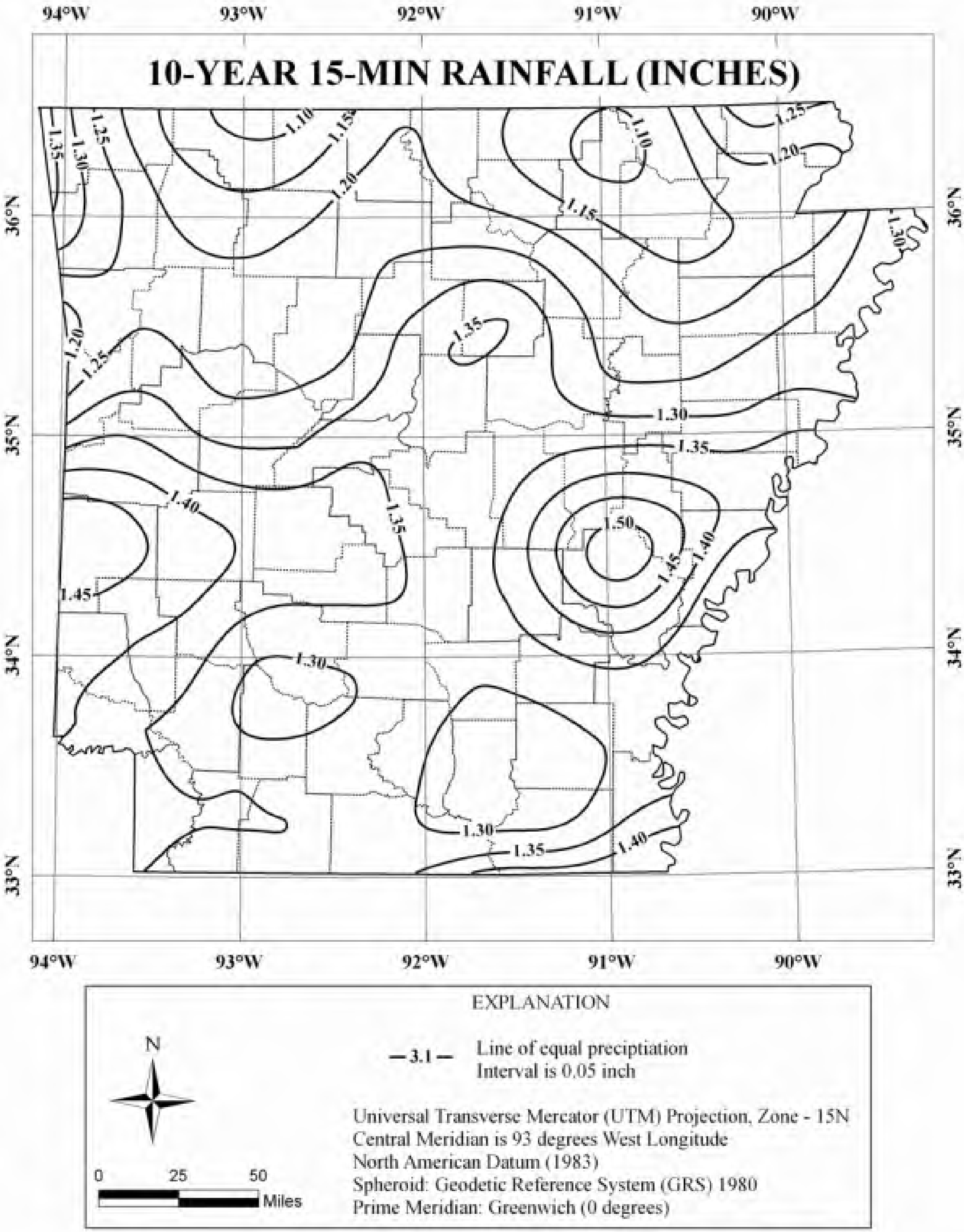

Figure 10. Depth of 10-year storm for 15-minute interval in Arkansas.

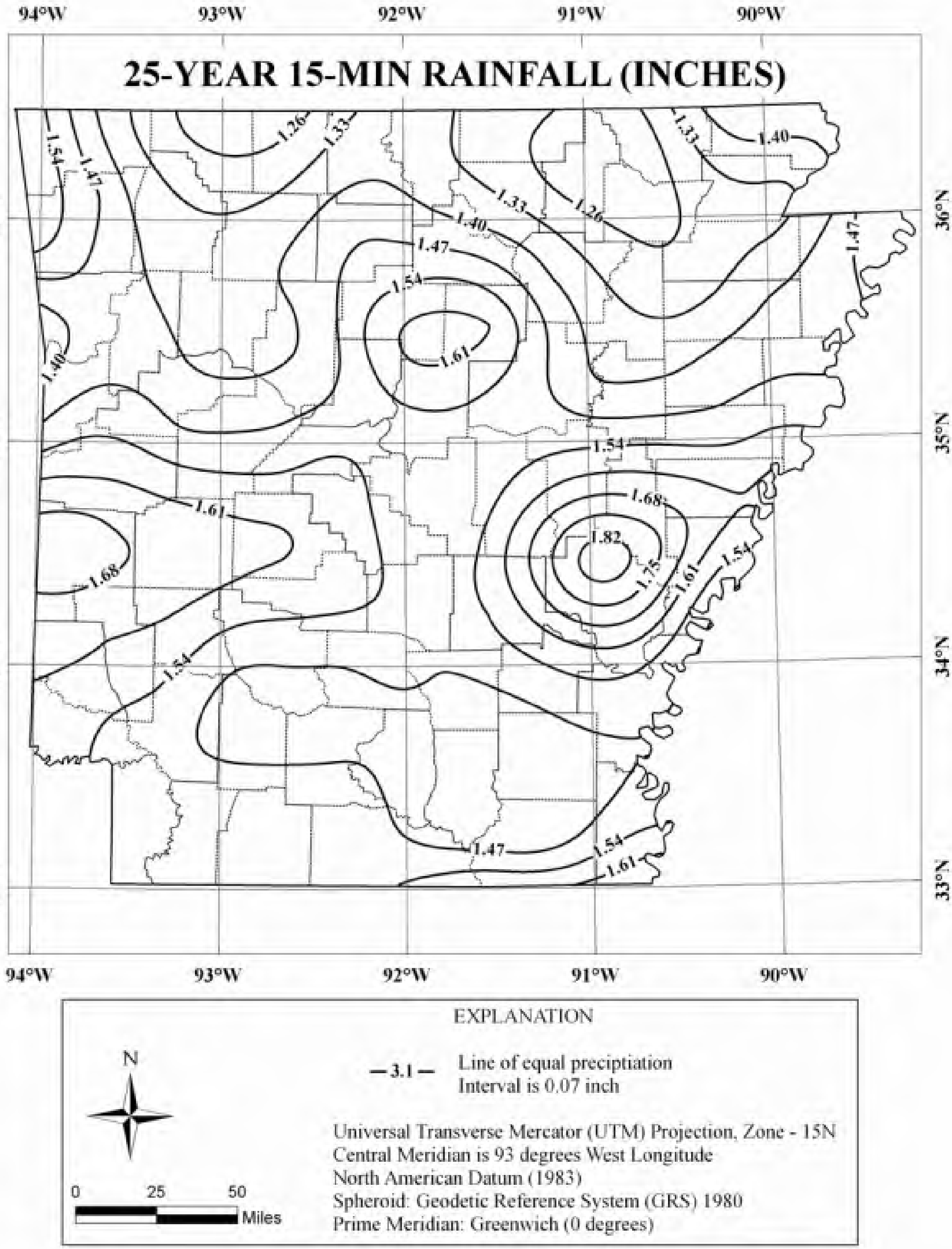

Figure 11. Depth of 25-year storm for 15-minute interval in Arkansas.

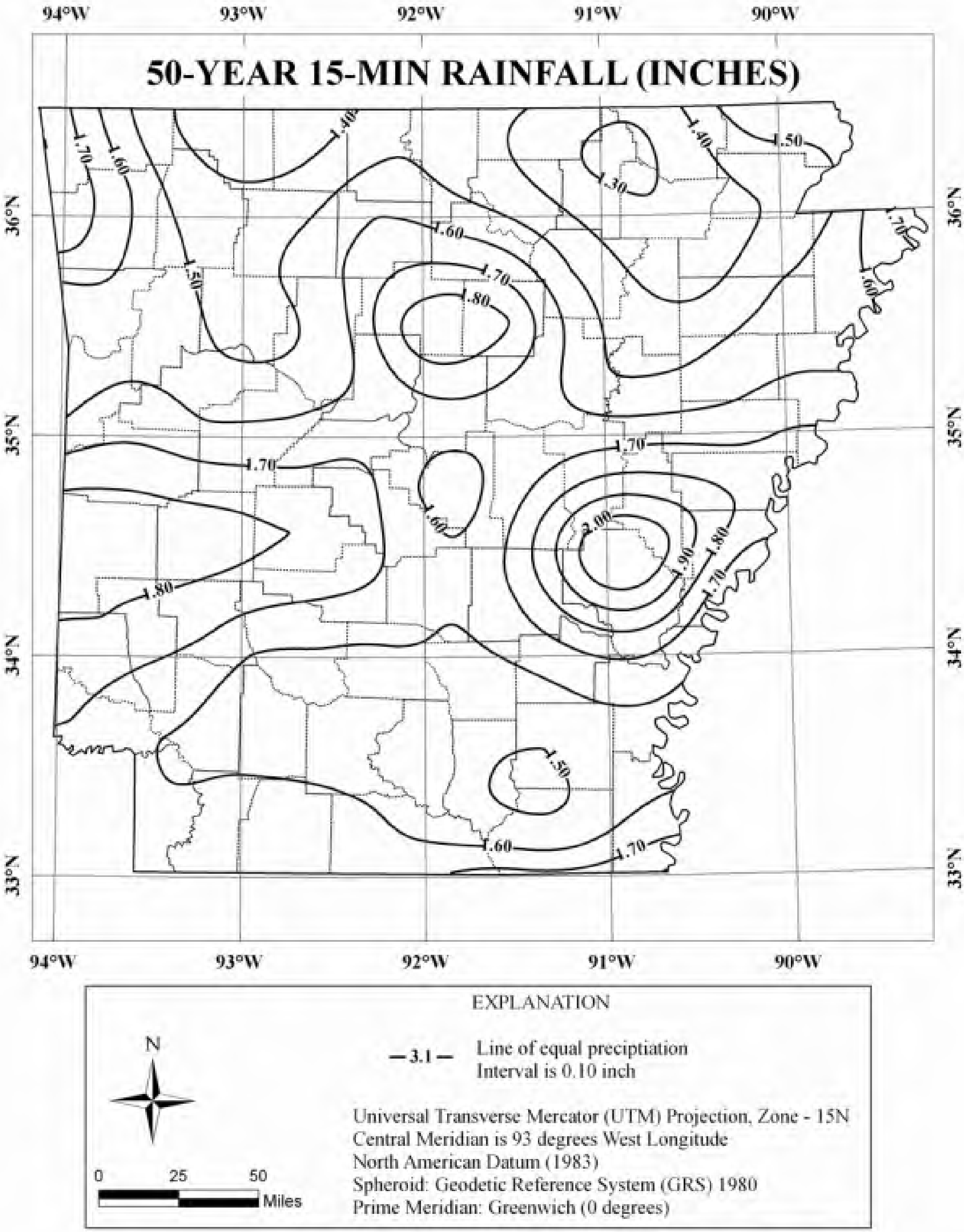

Figure 12. Depth of 50-year storm for 15-minute interval in Arkansas.

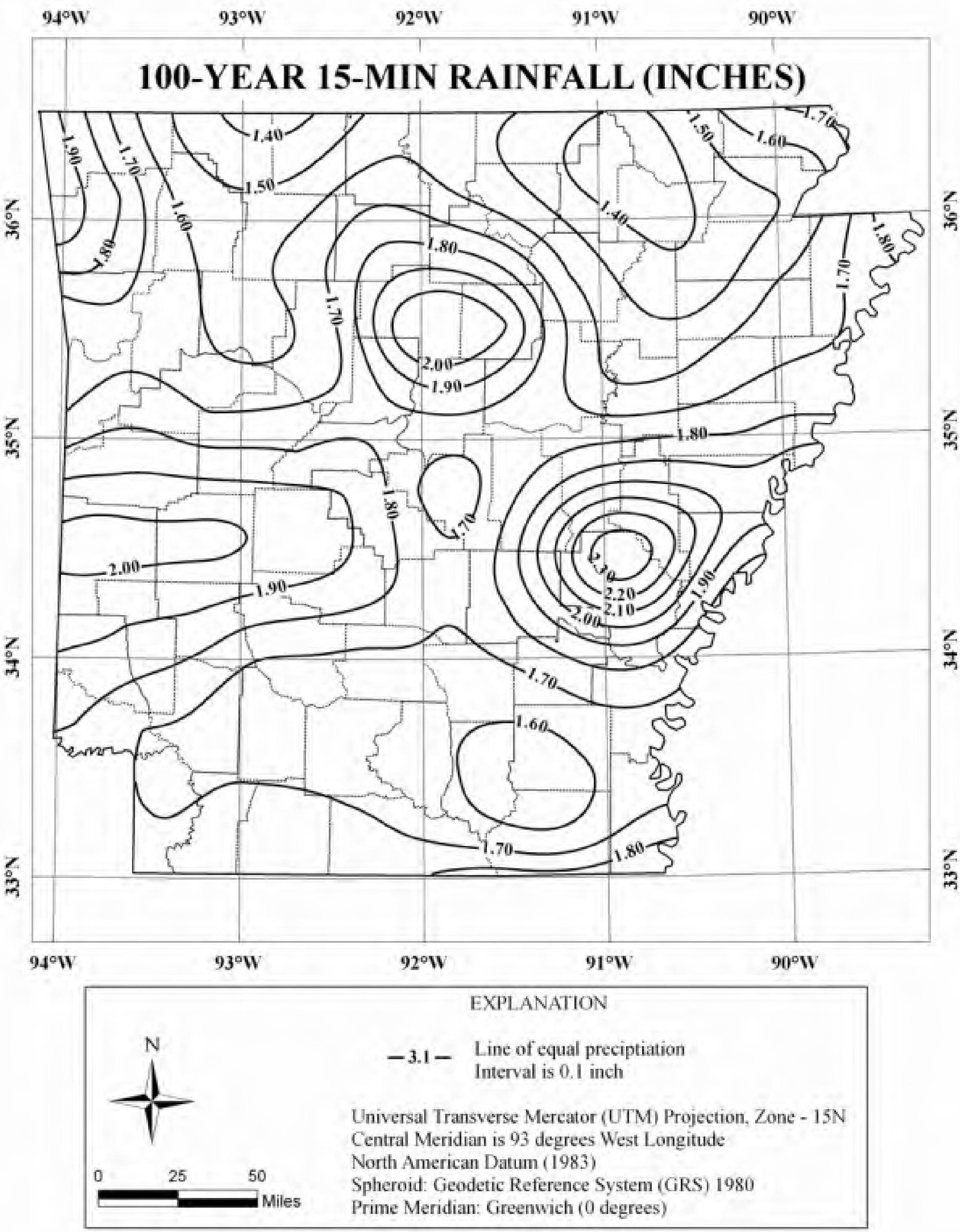

Figure 13. Depth of 100-year storm for 15-minute interval in Arkansas.

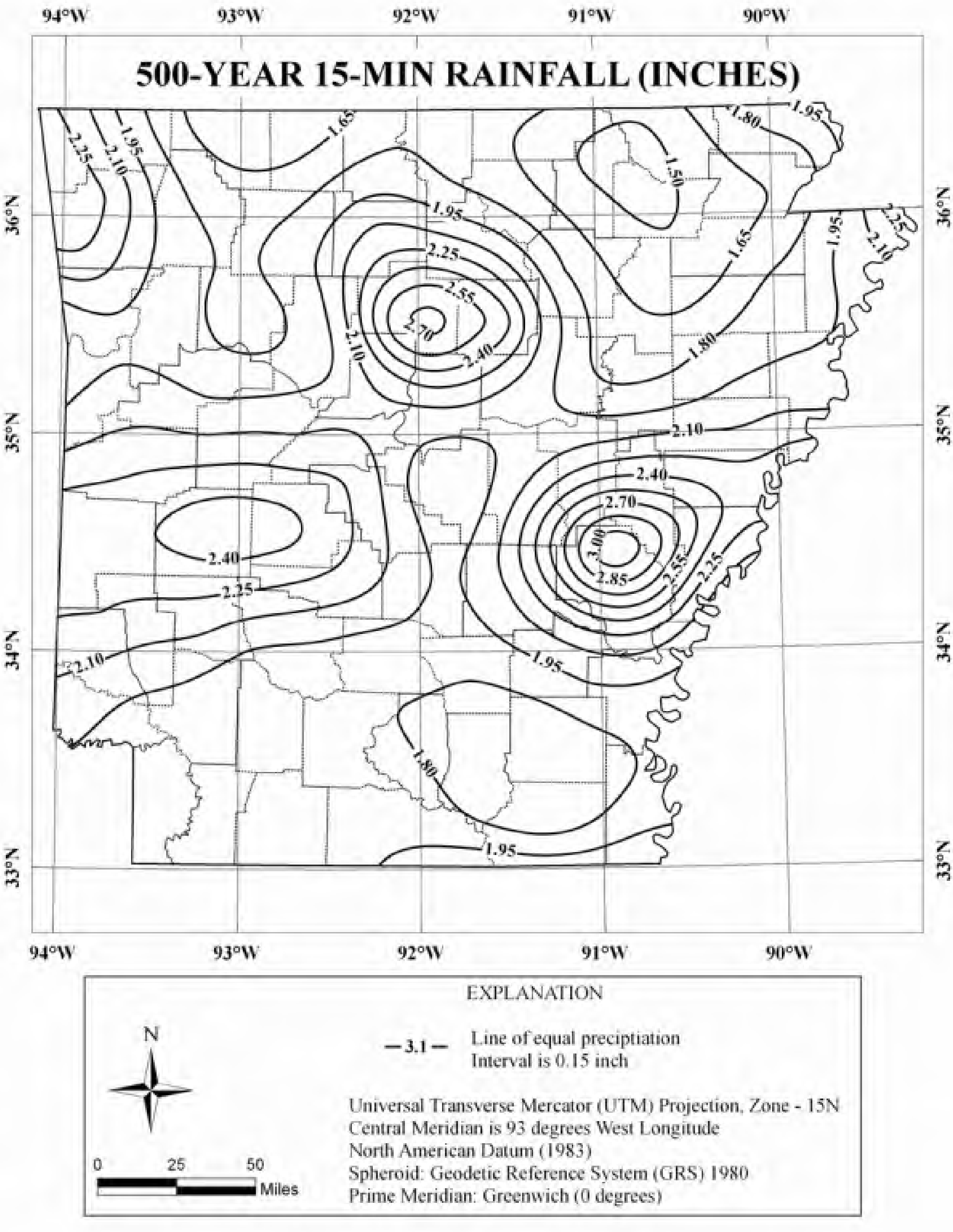

Figure 14. Depth of 500-year storm for 15-minute interval in Arkansas.

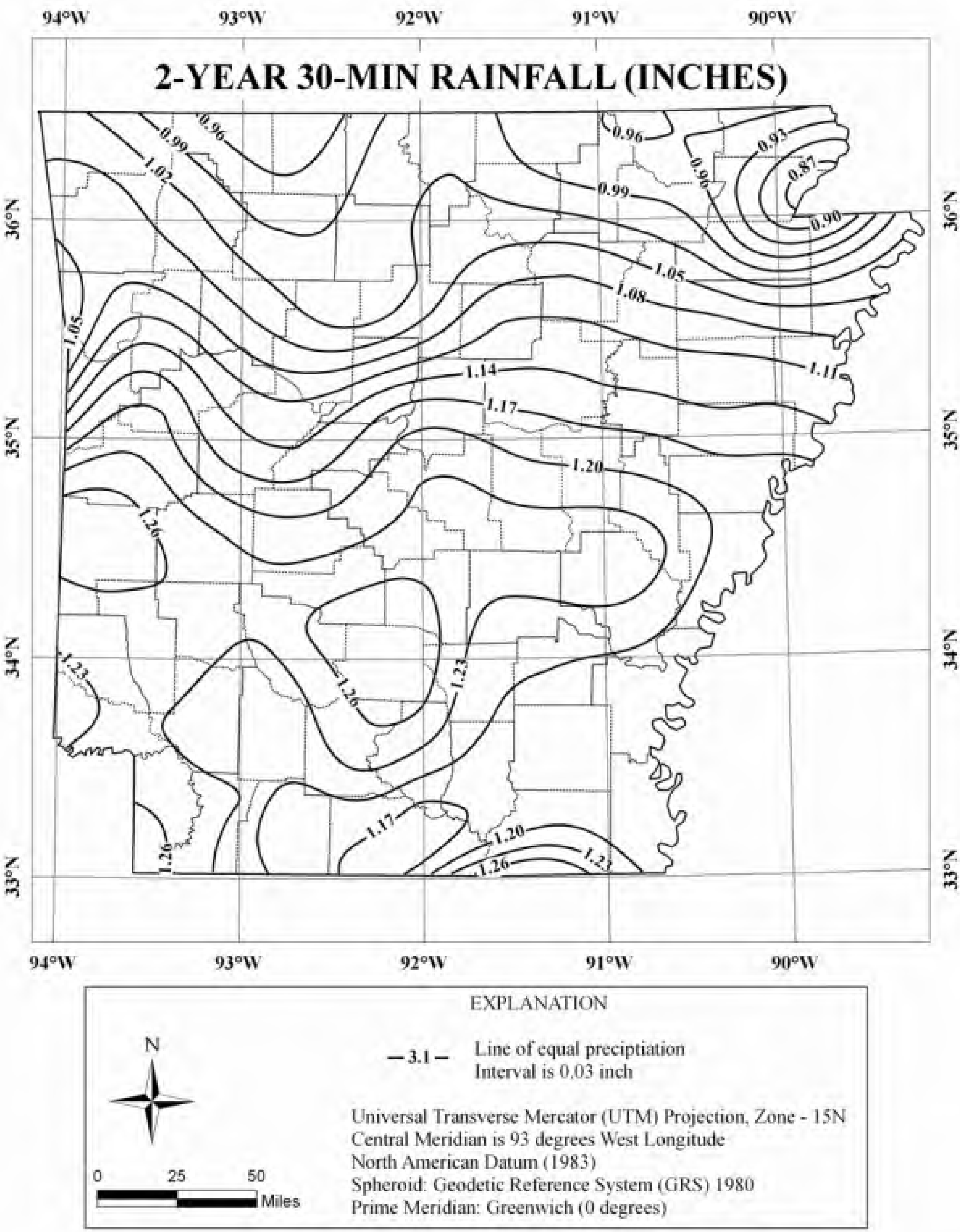

Figure 15. Depth of 2-year storm for 30-minute interval in Arkansas.

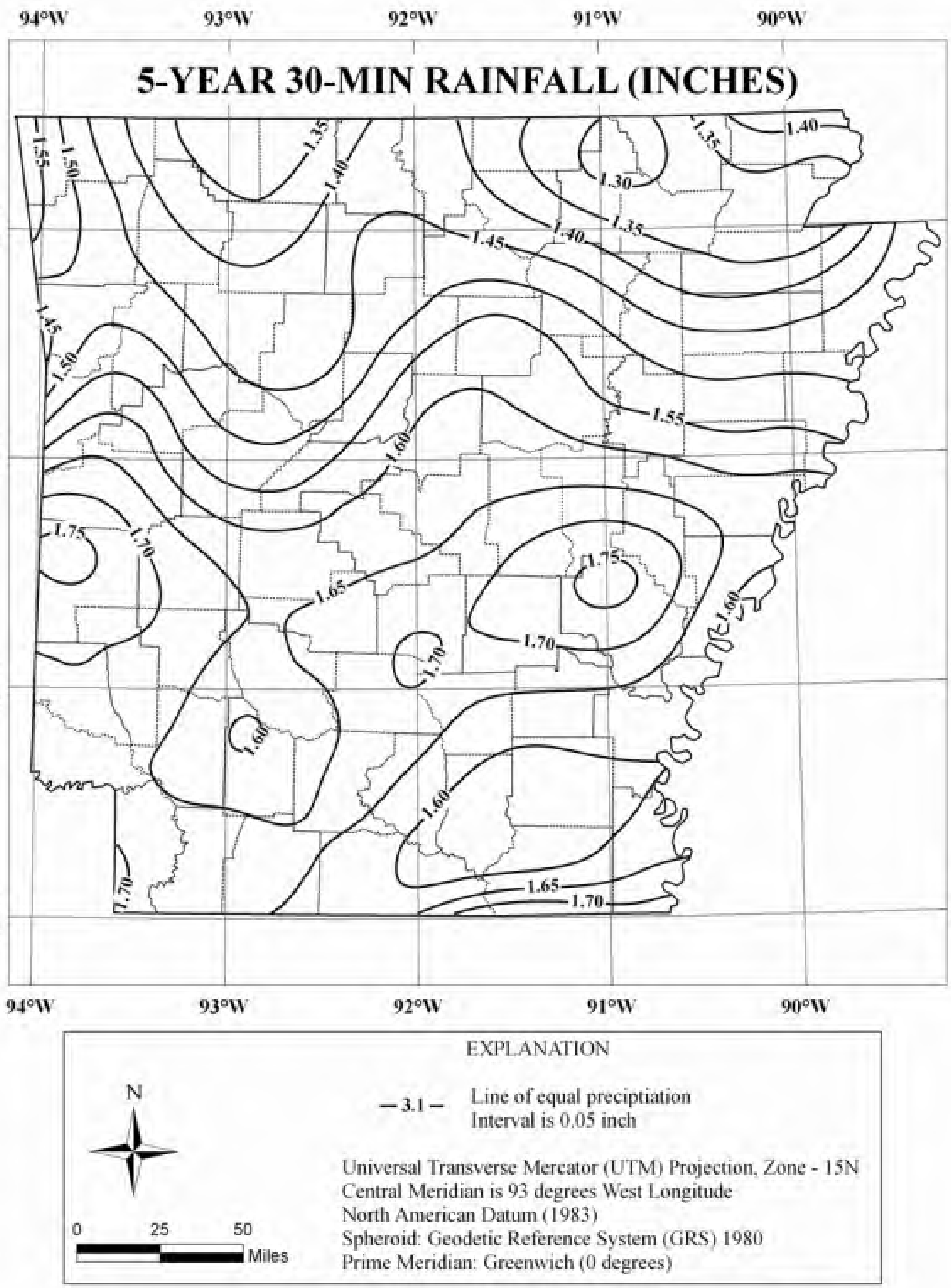

Figure 16. Depth of 5-year storm for 30-minute interval in Arkansas.

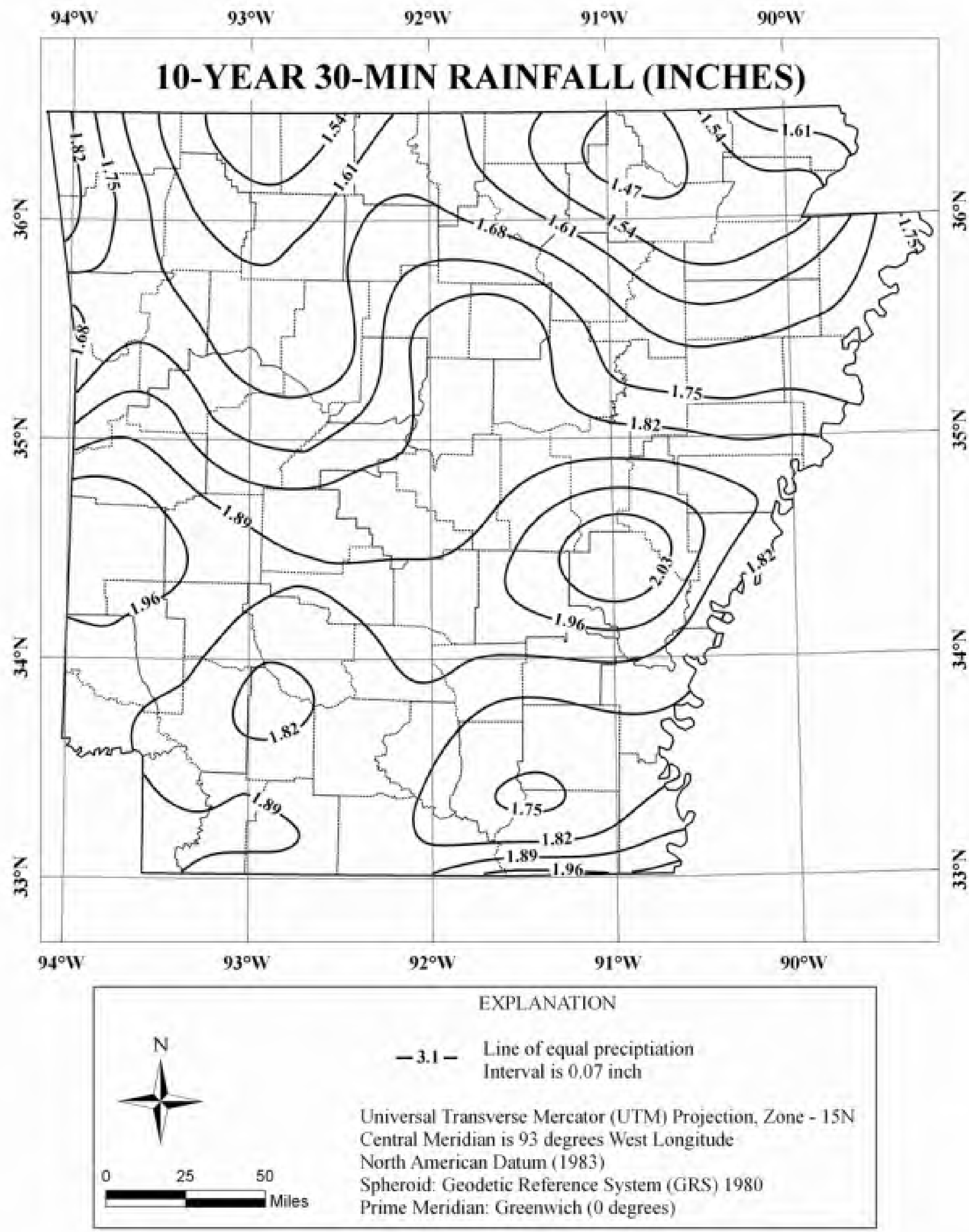

Figure 17. Depth of 10-year storm for 30-minute interval in Arkansas.

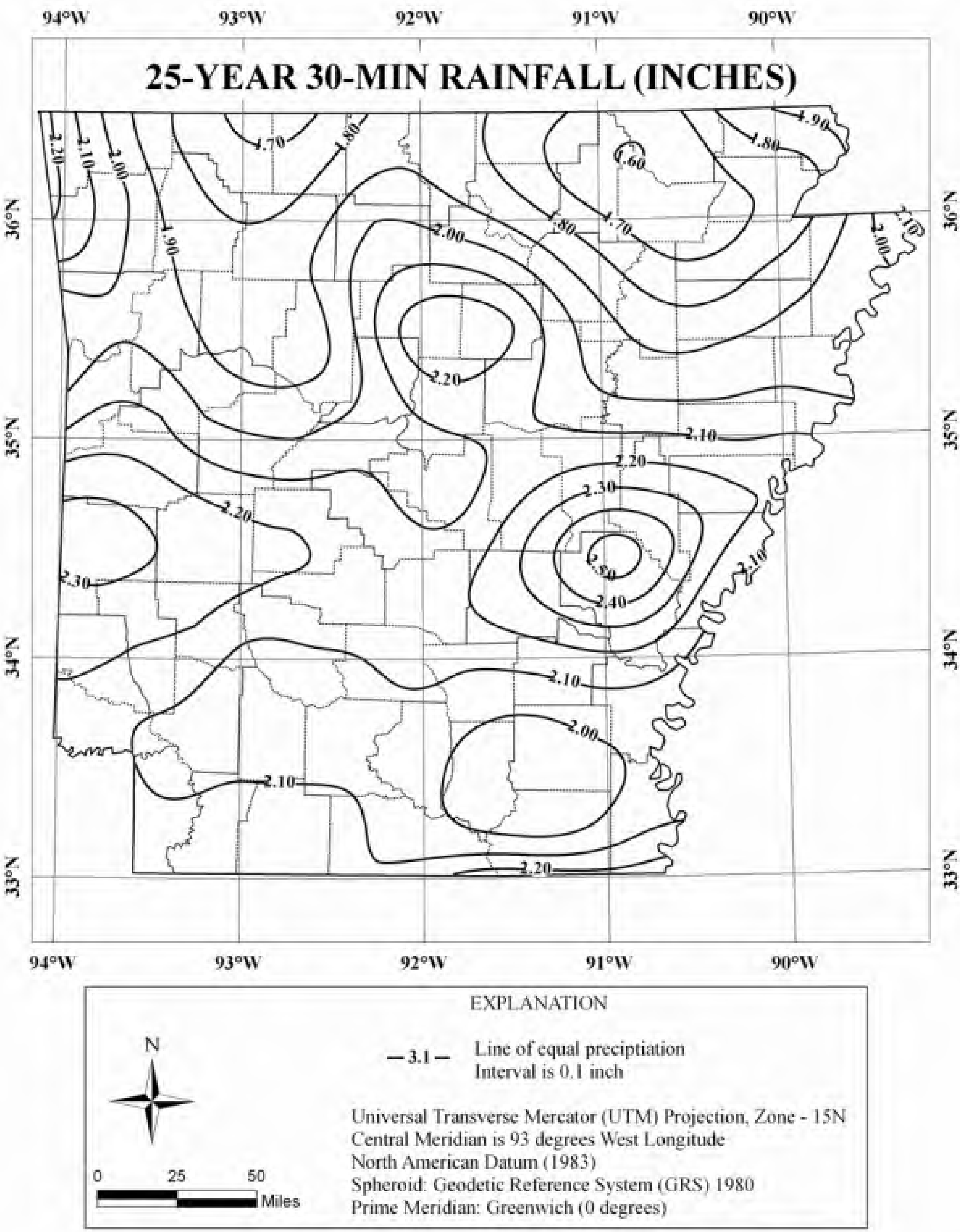

Figure 18. Depth of 25-year storm for 30-minute interval in Arkansas.

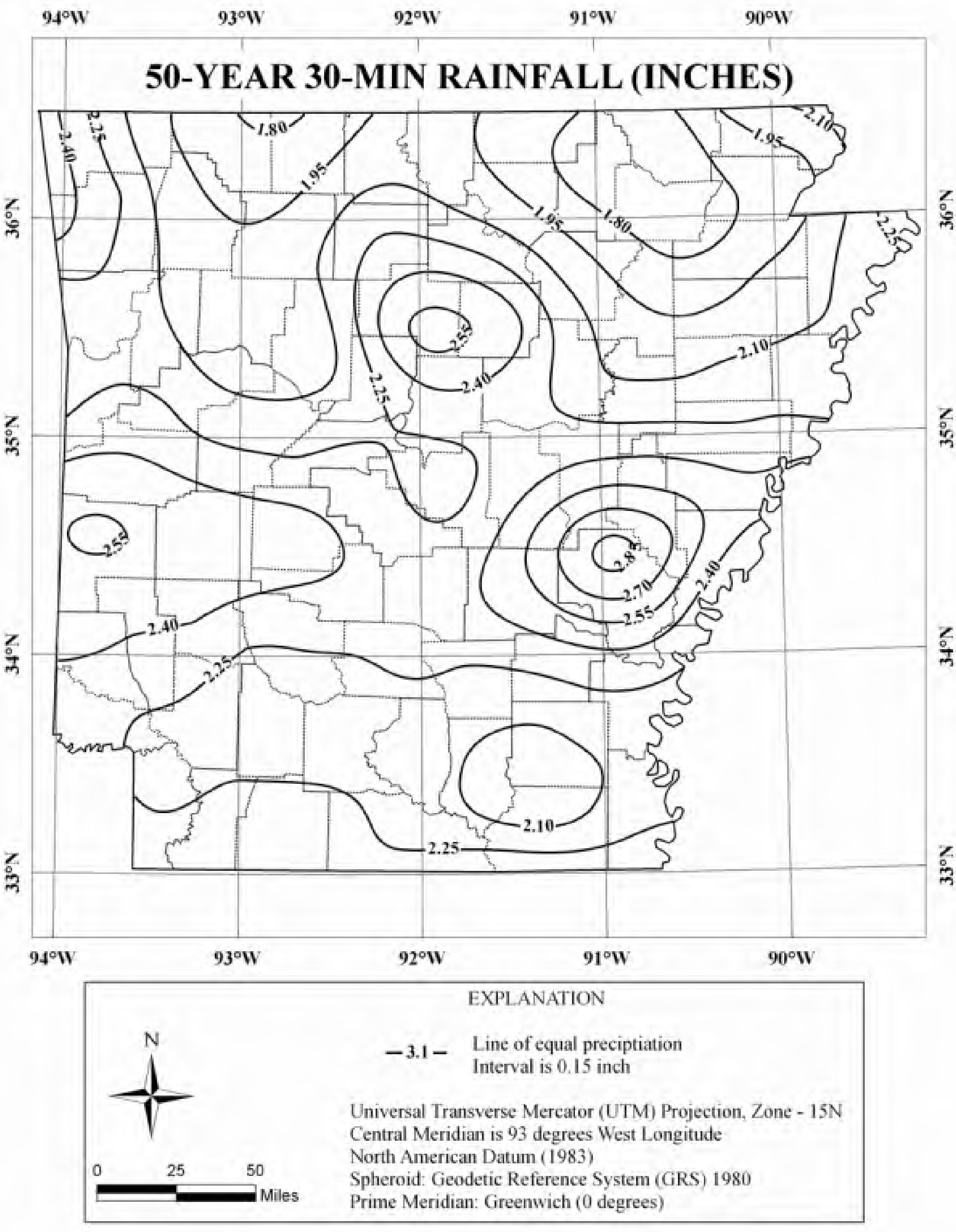

Figure 19. Depth of 50-year storm for 30-minute interval in Arkansas.

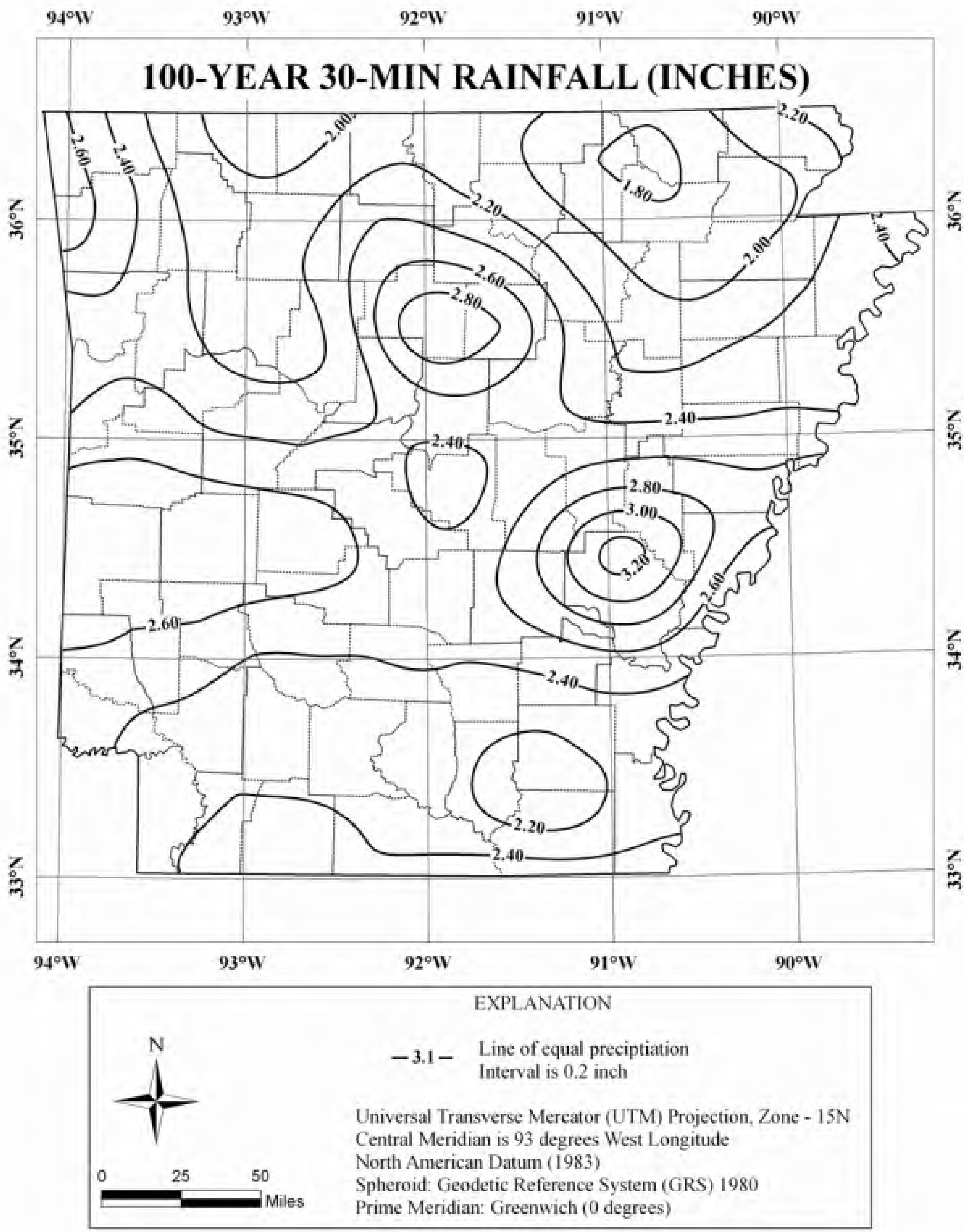

Figure 20. Depth of 100-year storm for 30-minute interval in Arkansas.

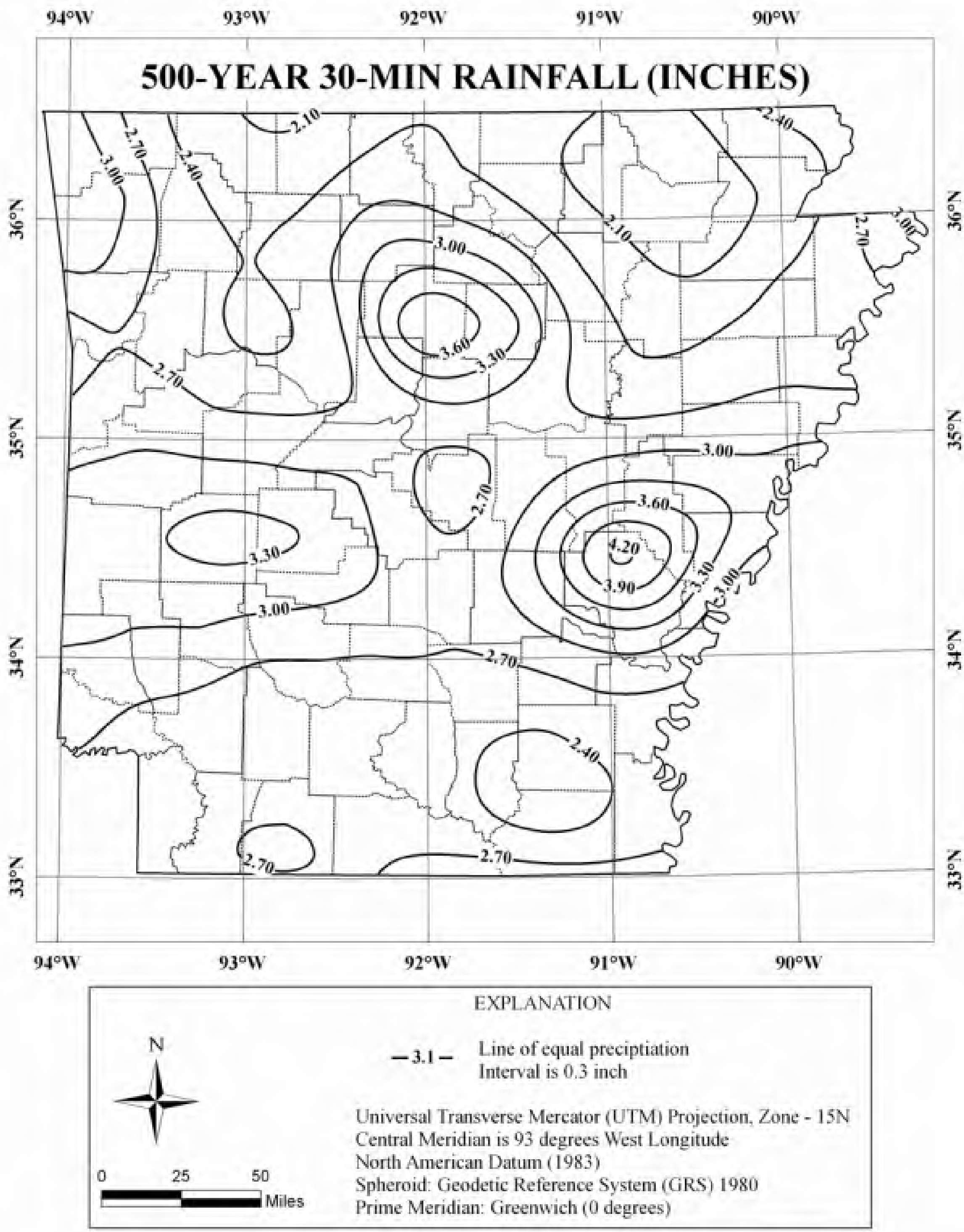

Figure 21. Depth of 500-year storm for 30-minute interval in Arkansas.

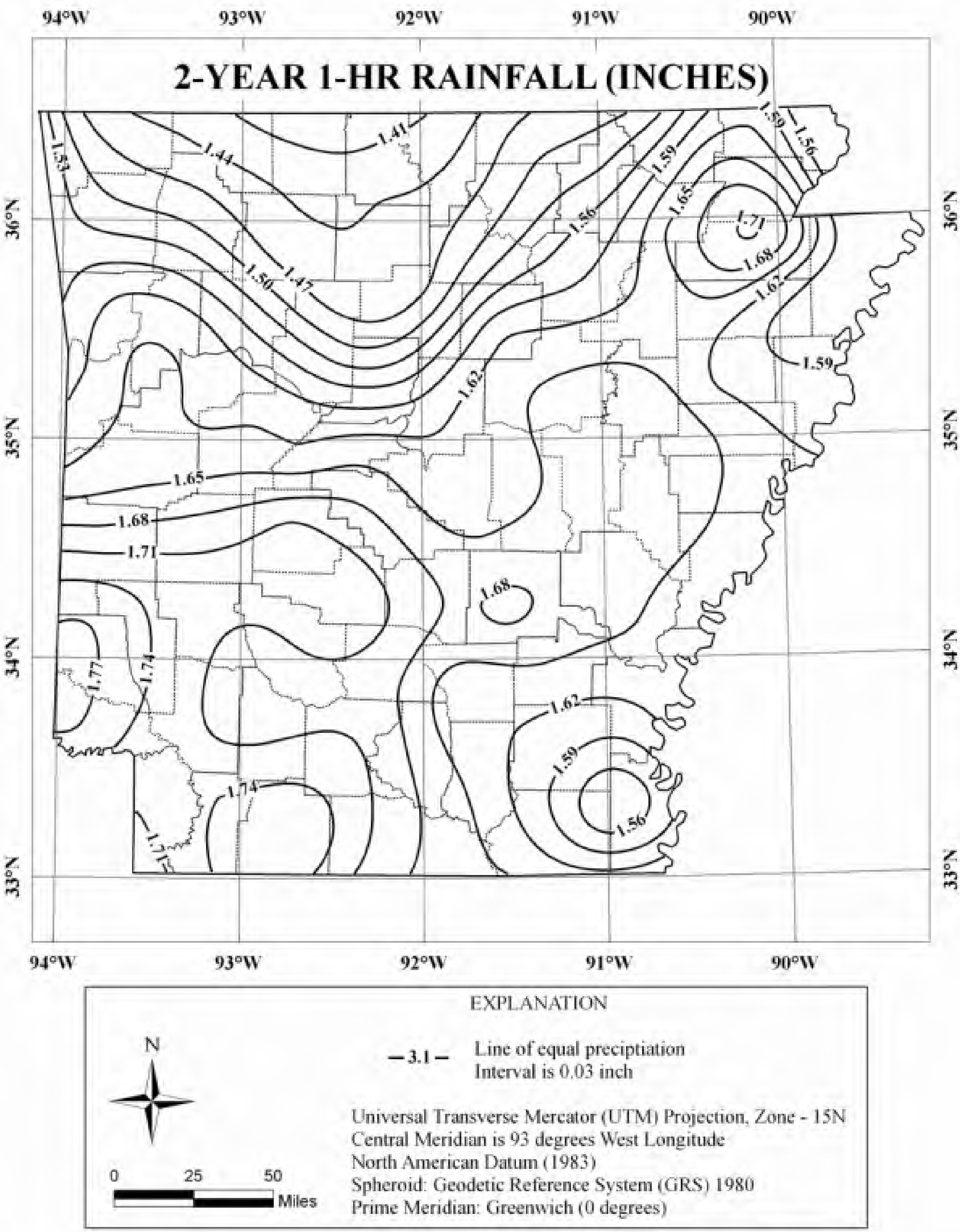

Figure 22. Depth of 2-year storm for 1-hour interval in Arkansas.

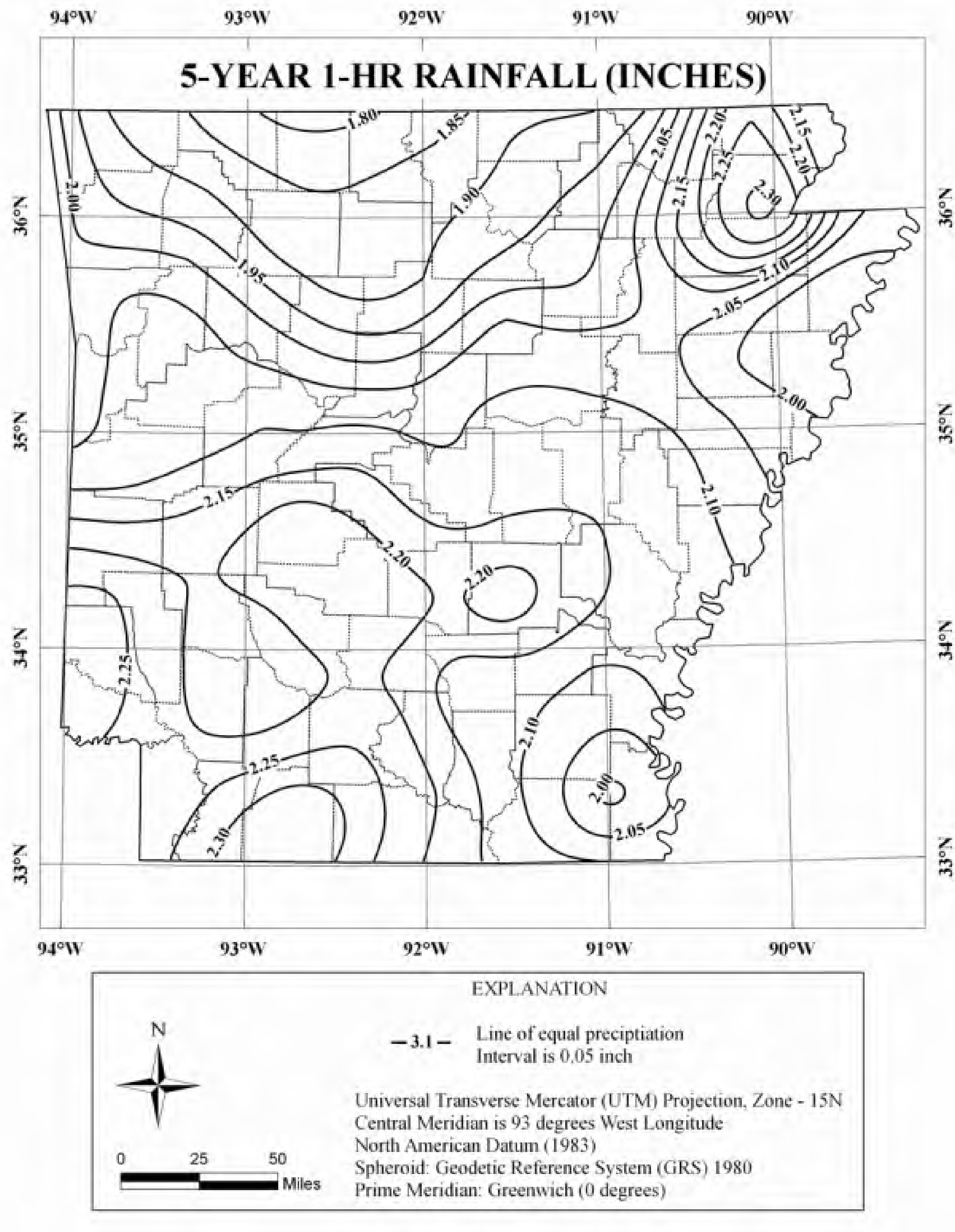

Figure 23. Depth of 5-year storm for 1-hour interval in Arkansas.

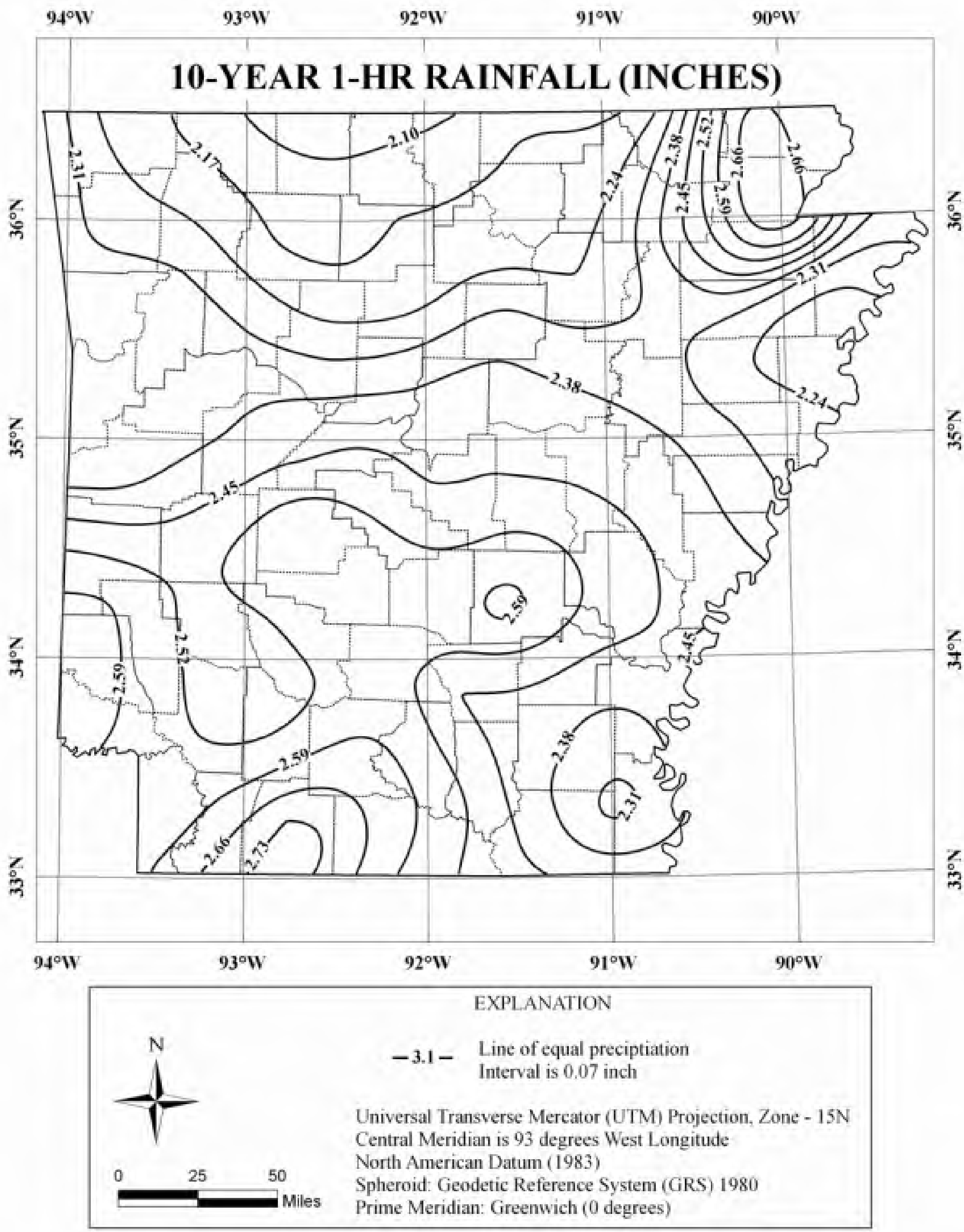

Figure 24. Depth of 10-year storm for 1-hour interval in Arkansas.

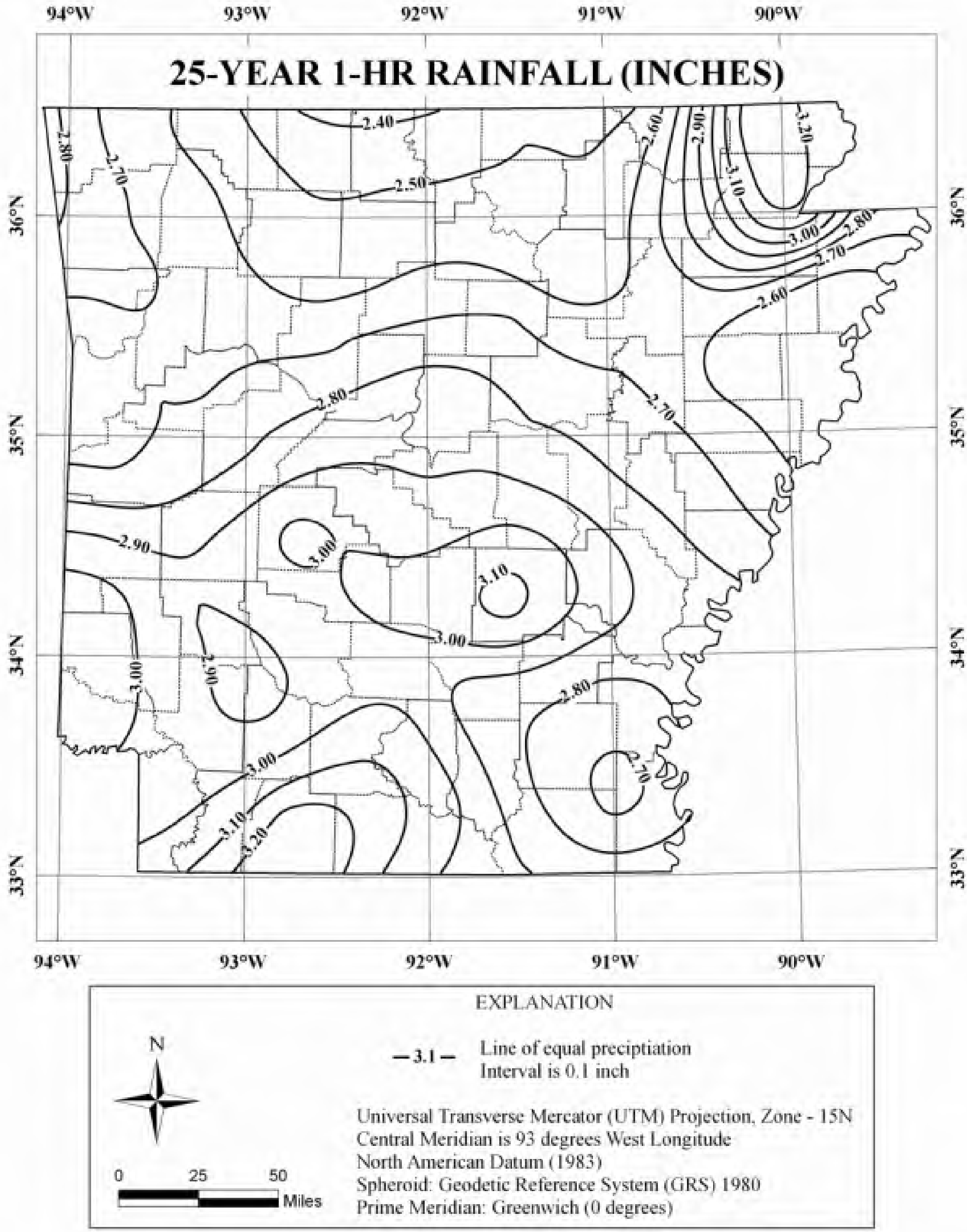

Figure 25. Depth of 25-year storm for 1-hour interval in Arkansas.

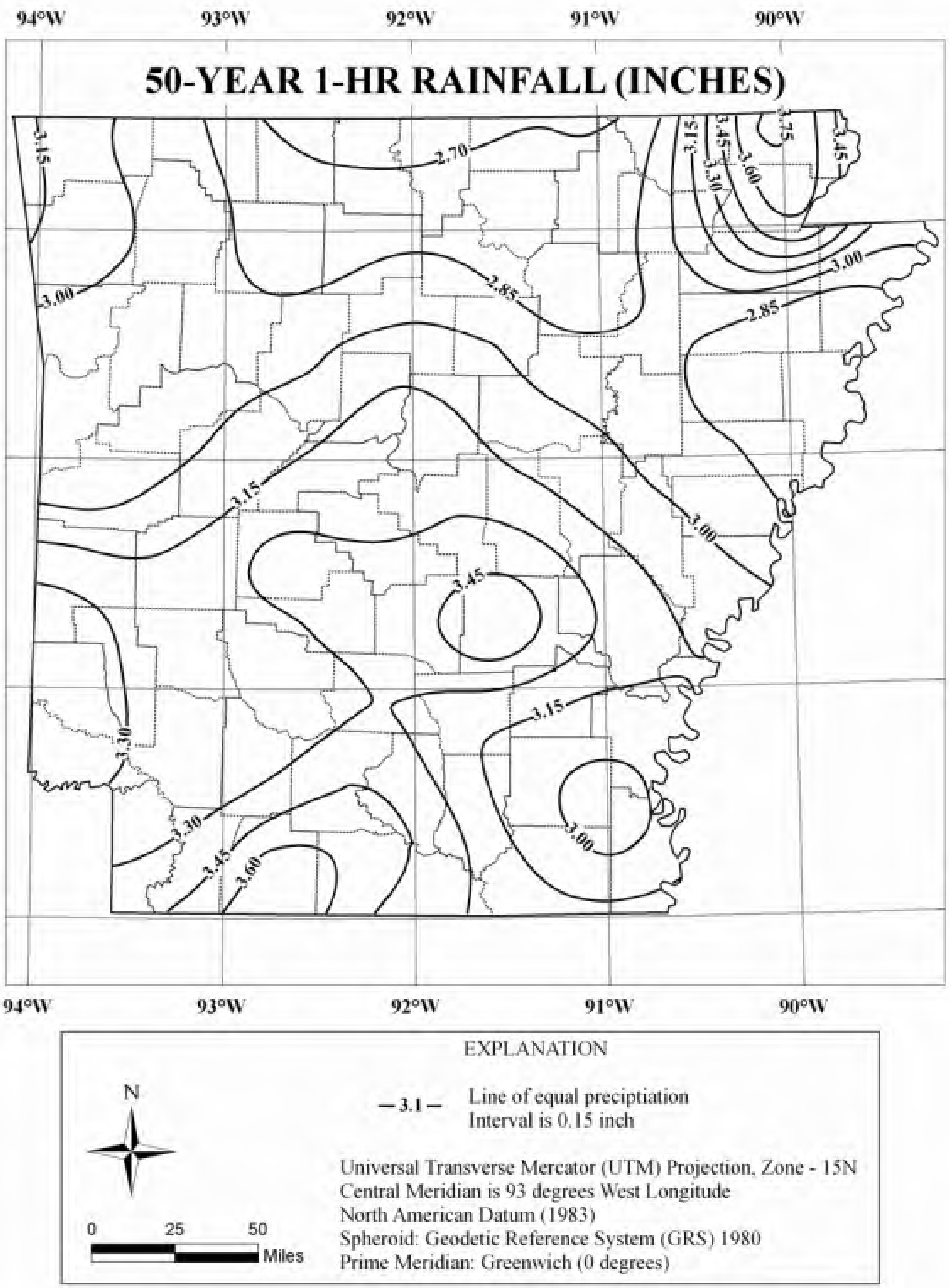

Figure 26. Depth of 50-year storm for 1-hour interval in Arkansas.

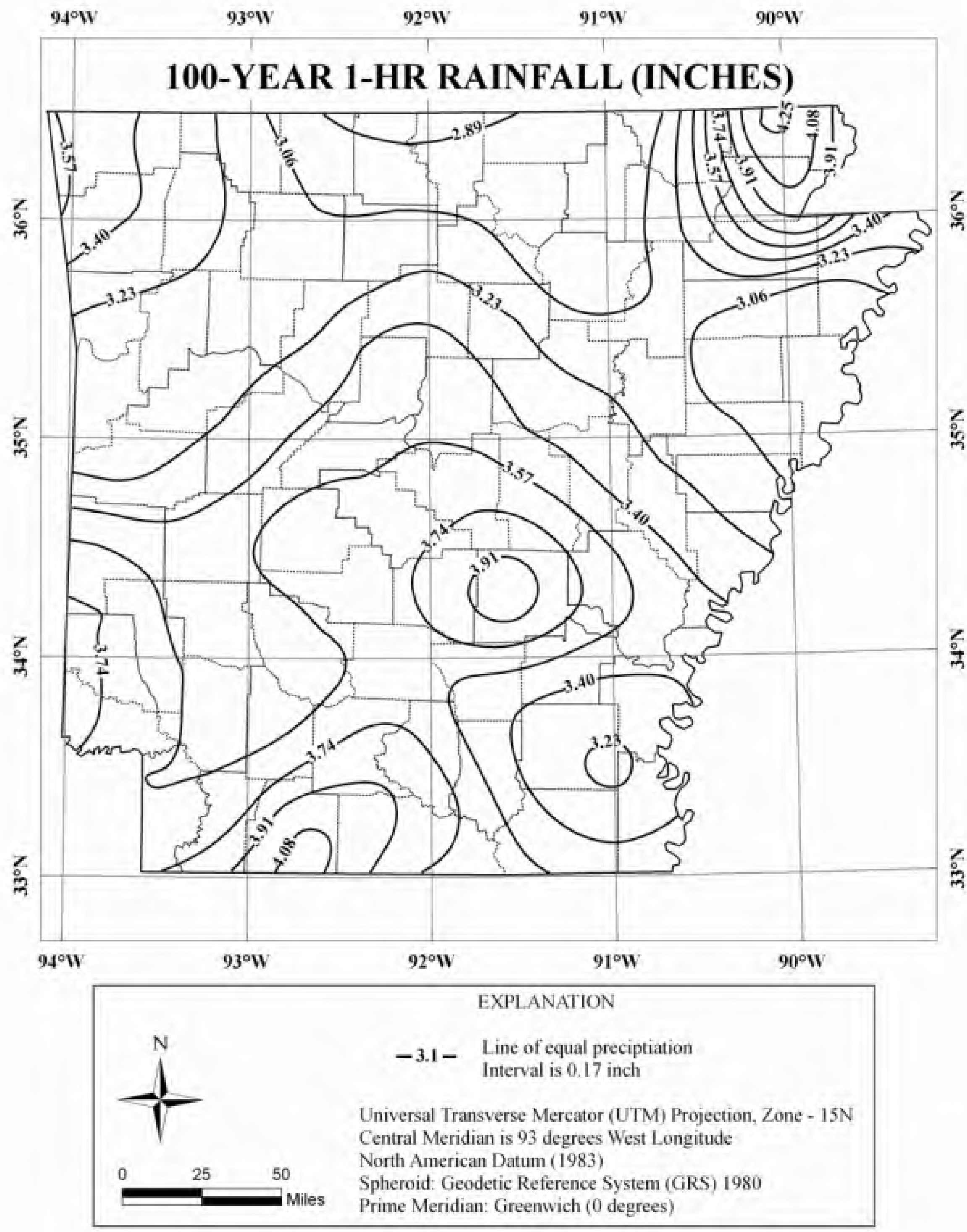

Figure 27. Depth of 100-year storm for 1-hour interval in Arkansas.

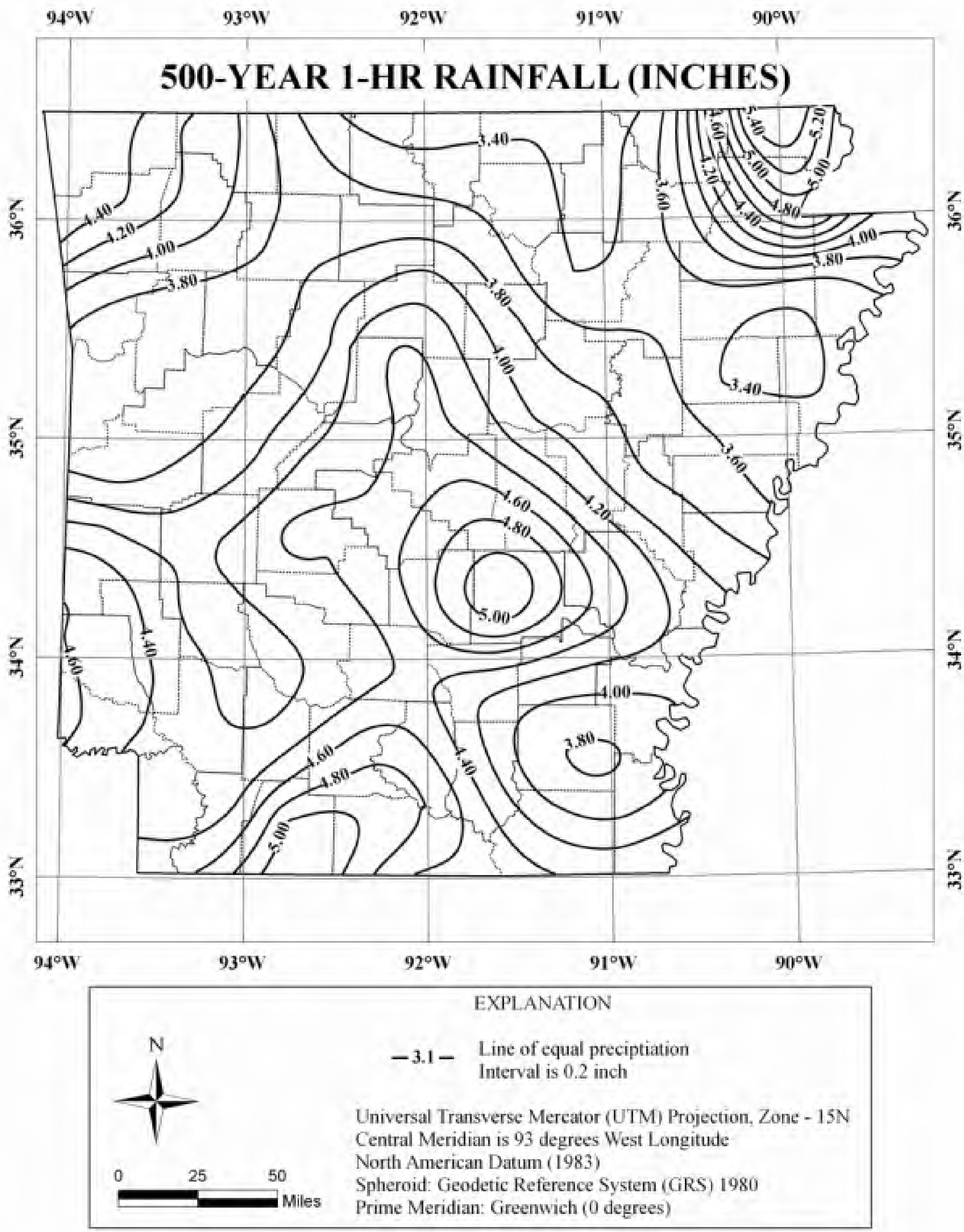

Figure 28. Depth of 500-year storm for 1-hour interval in Arkansas.

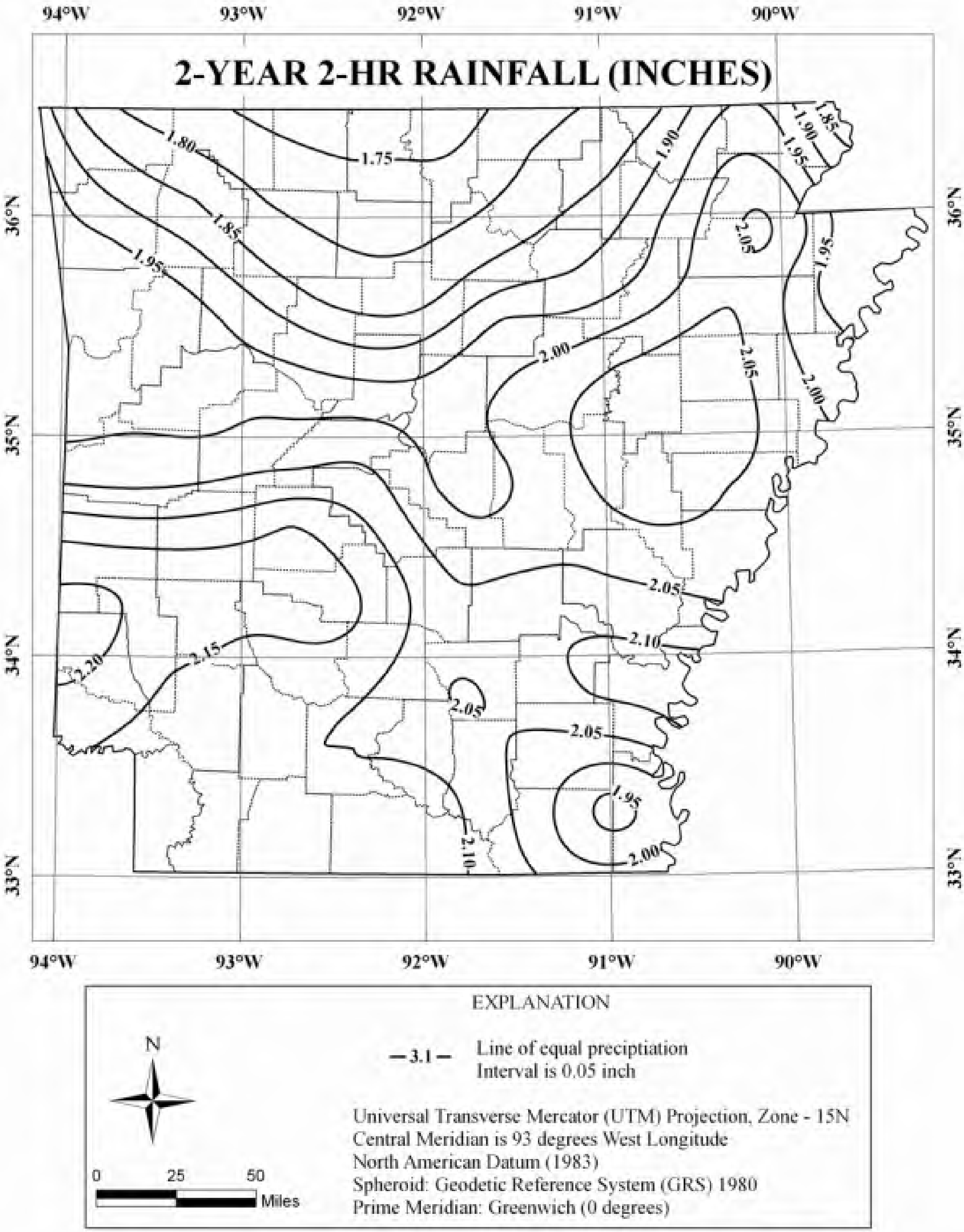

Figure 29. Depth of 2-year storm for 2-hour interval in Arkansas.

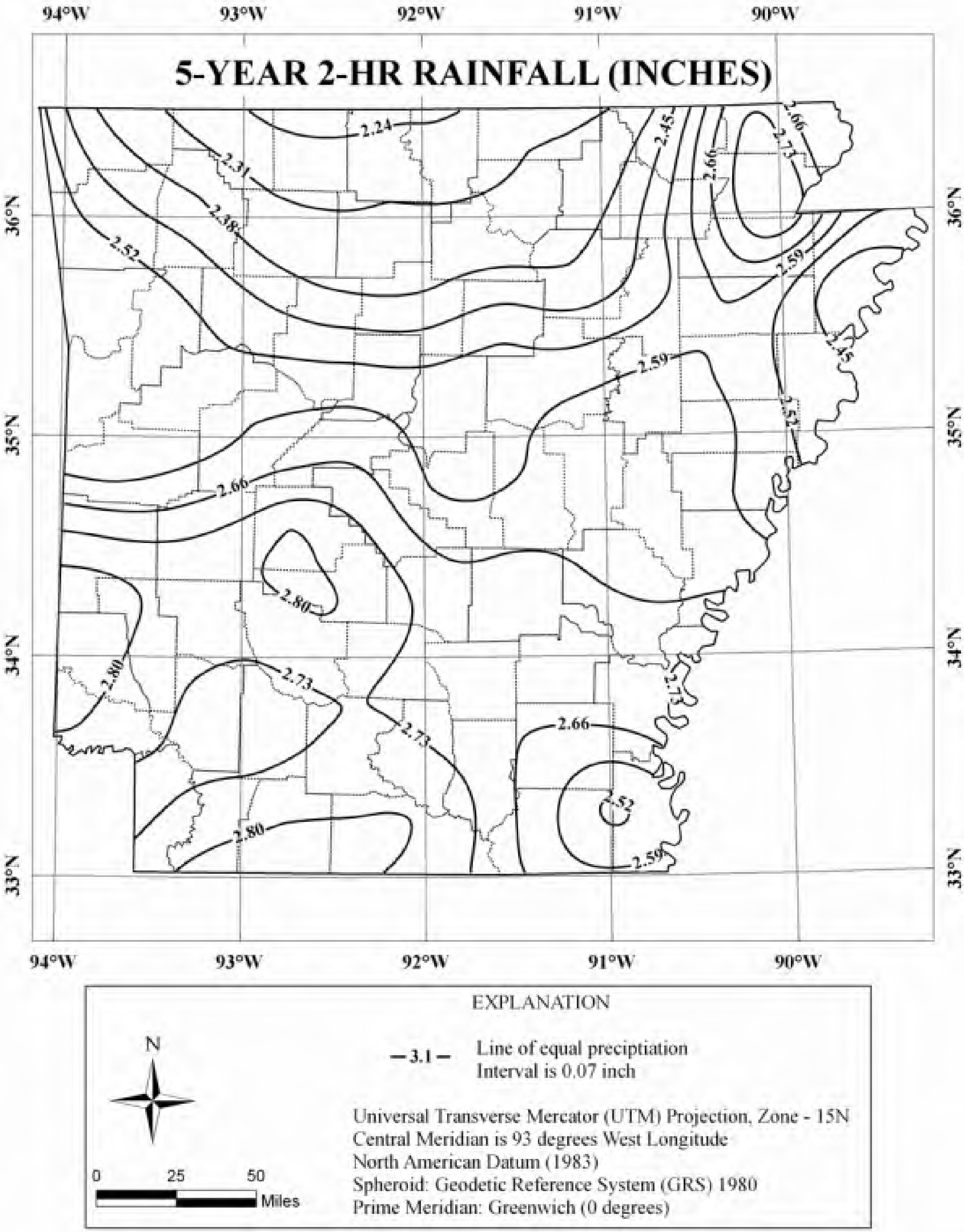

Figure 30. Depth of 5-year storm for 2-hour interval in Arkansas.

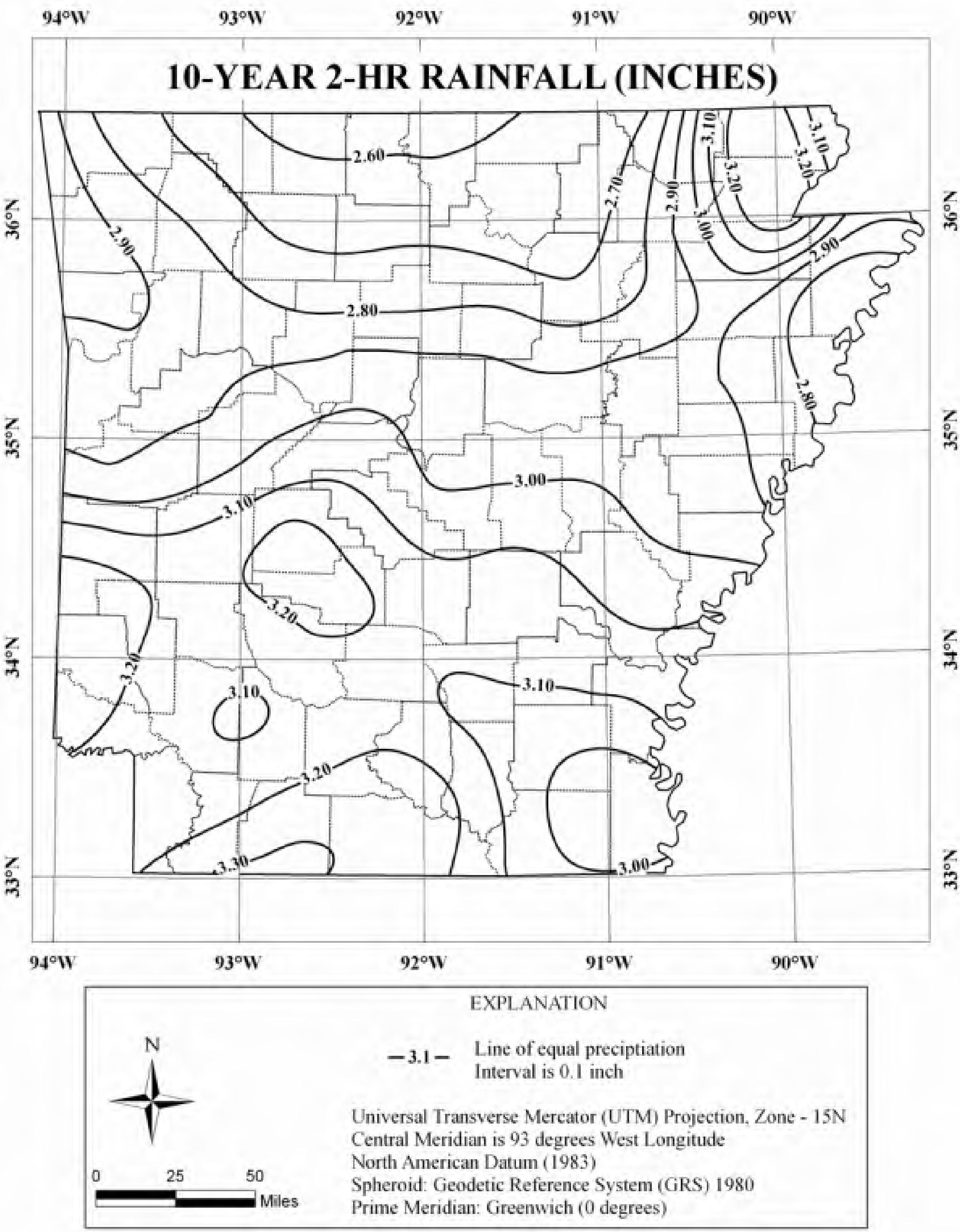

Figure 31. Depth of 10-year storm for 2-hour interval in Arkansas.

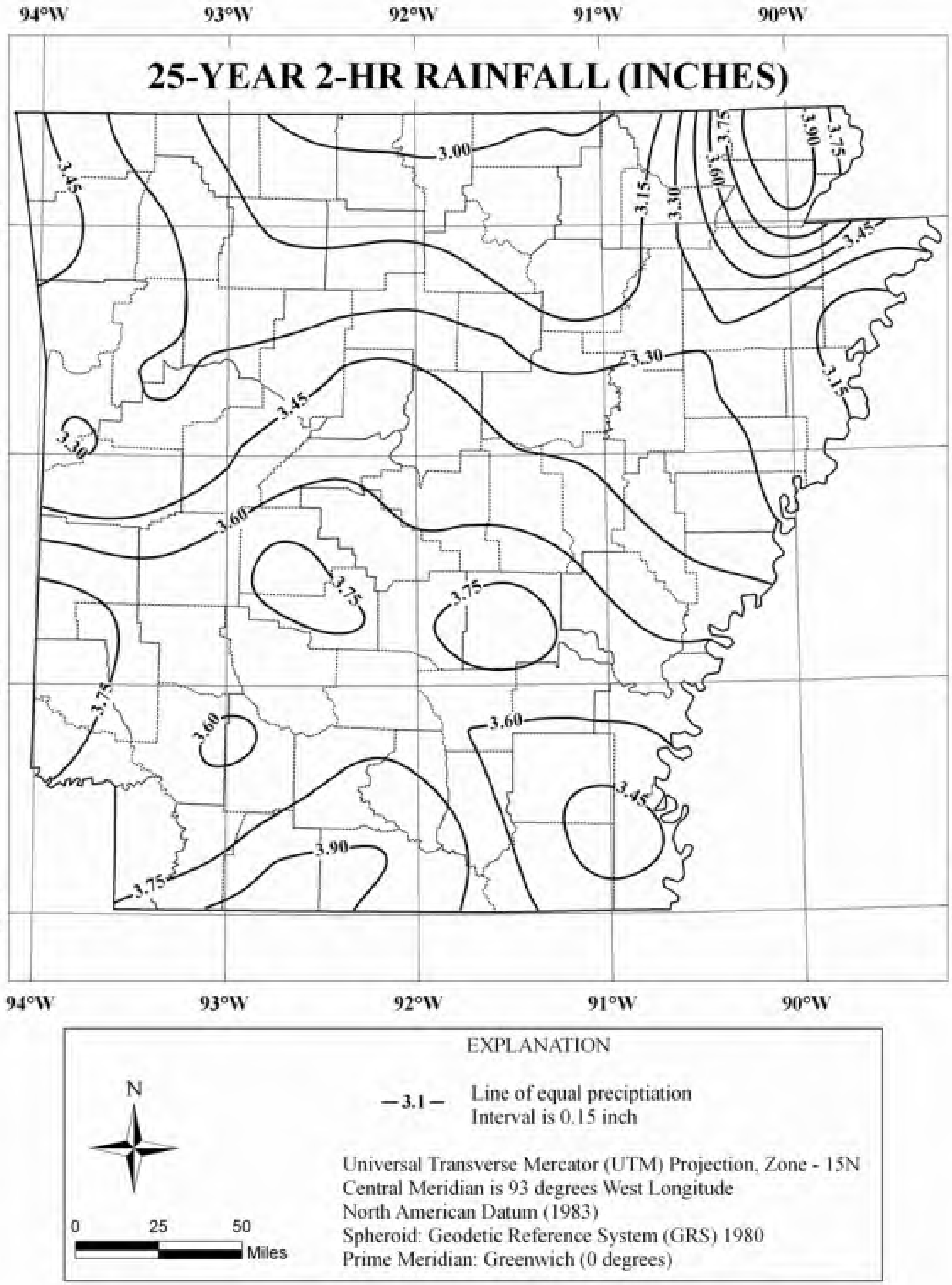

Figure 32. Depth of 25-year storm for 2-hour interval in Arkansas.

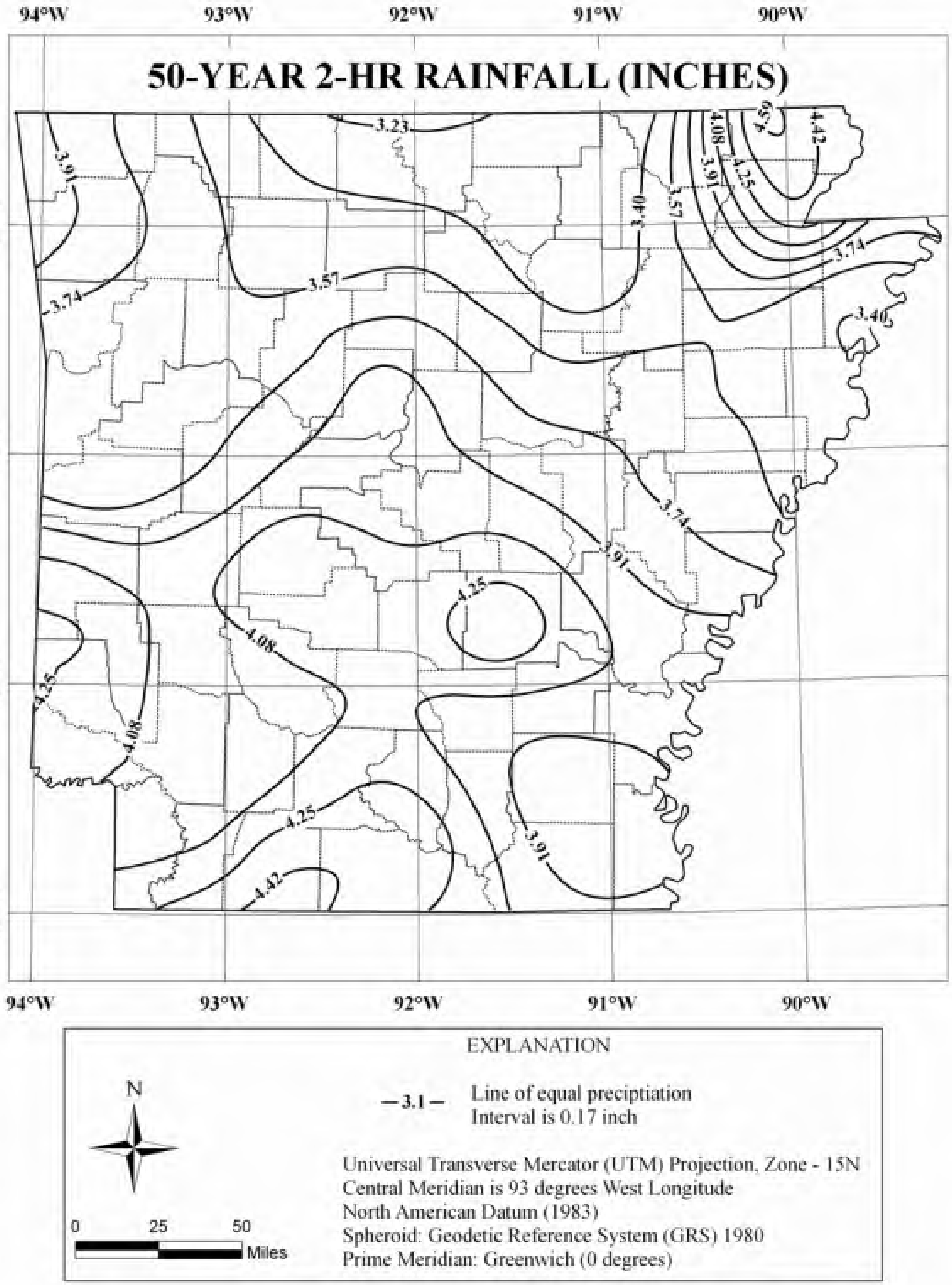

Figure 33. Depth of 50-year storm for 2-hour interval in Arkansas.

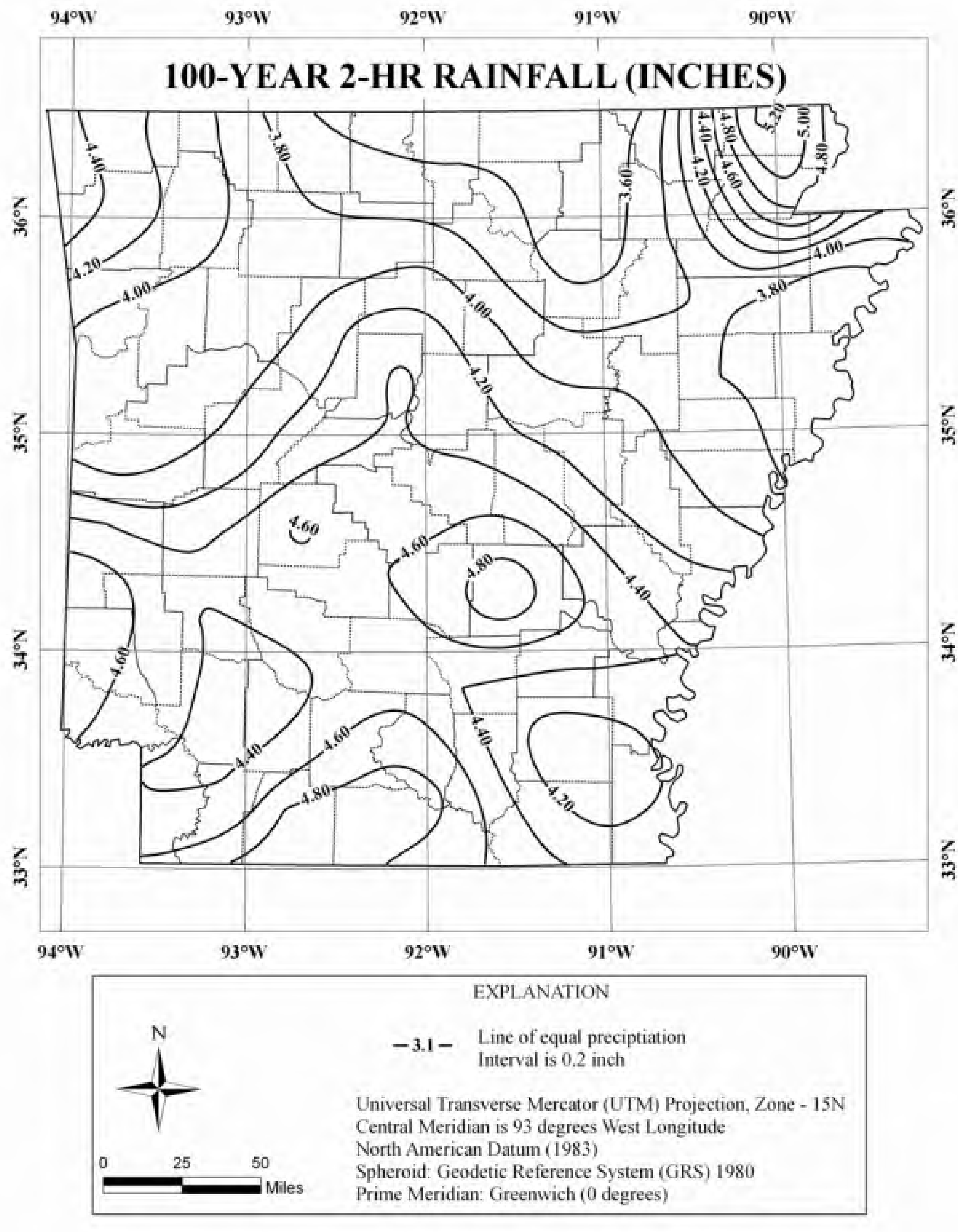

Figure 34. Depth of 100-year storm for 2-hour interval in Arkansas.

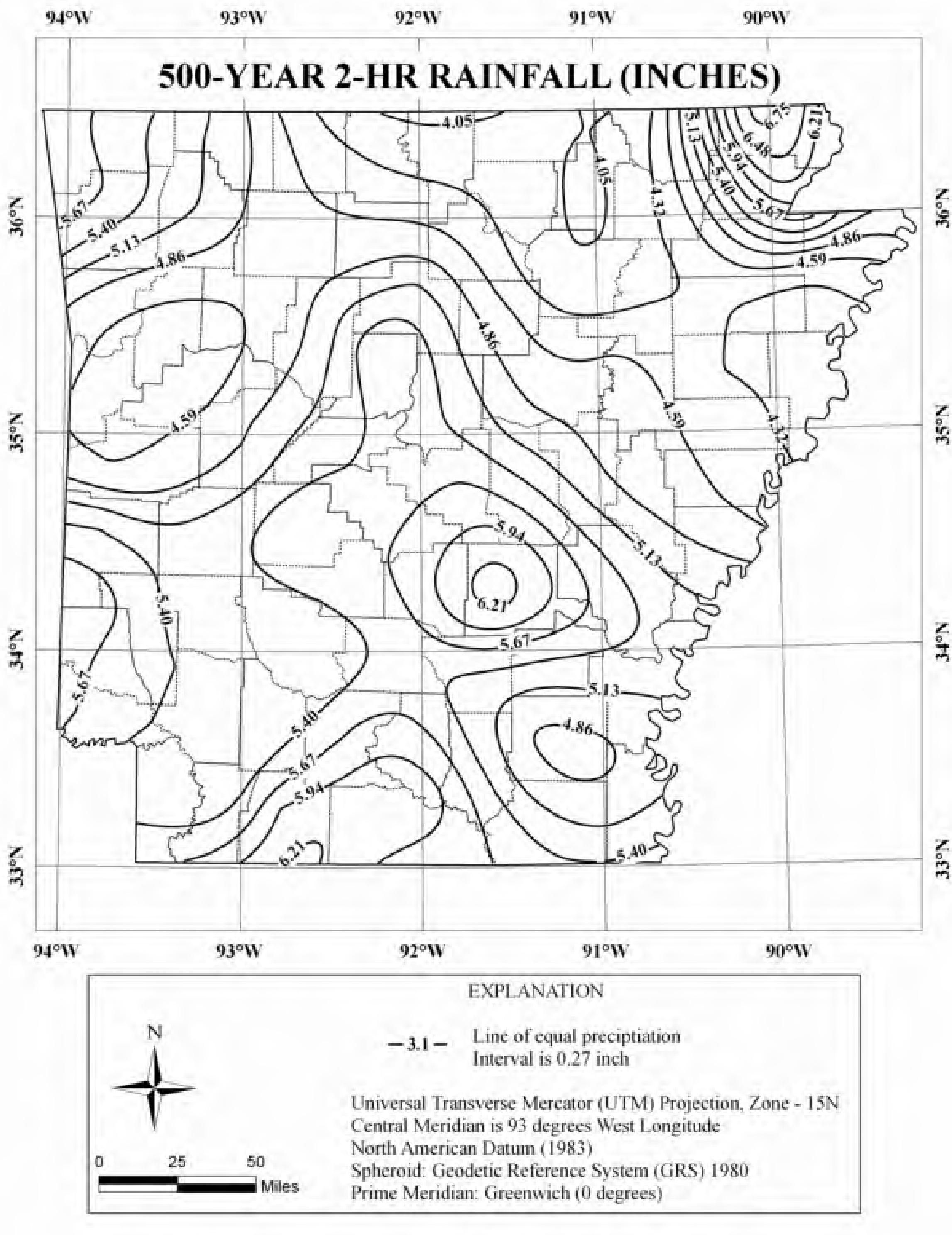

Figure 35. Depth of 500-year storm for 2-hour interval in Arkansas.

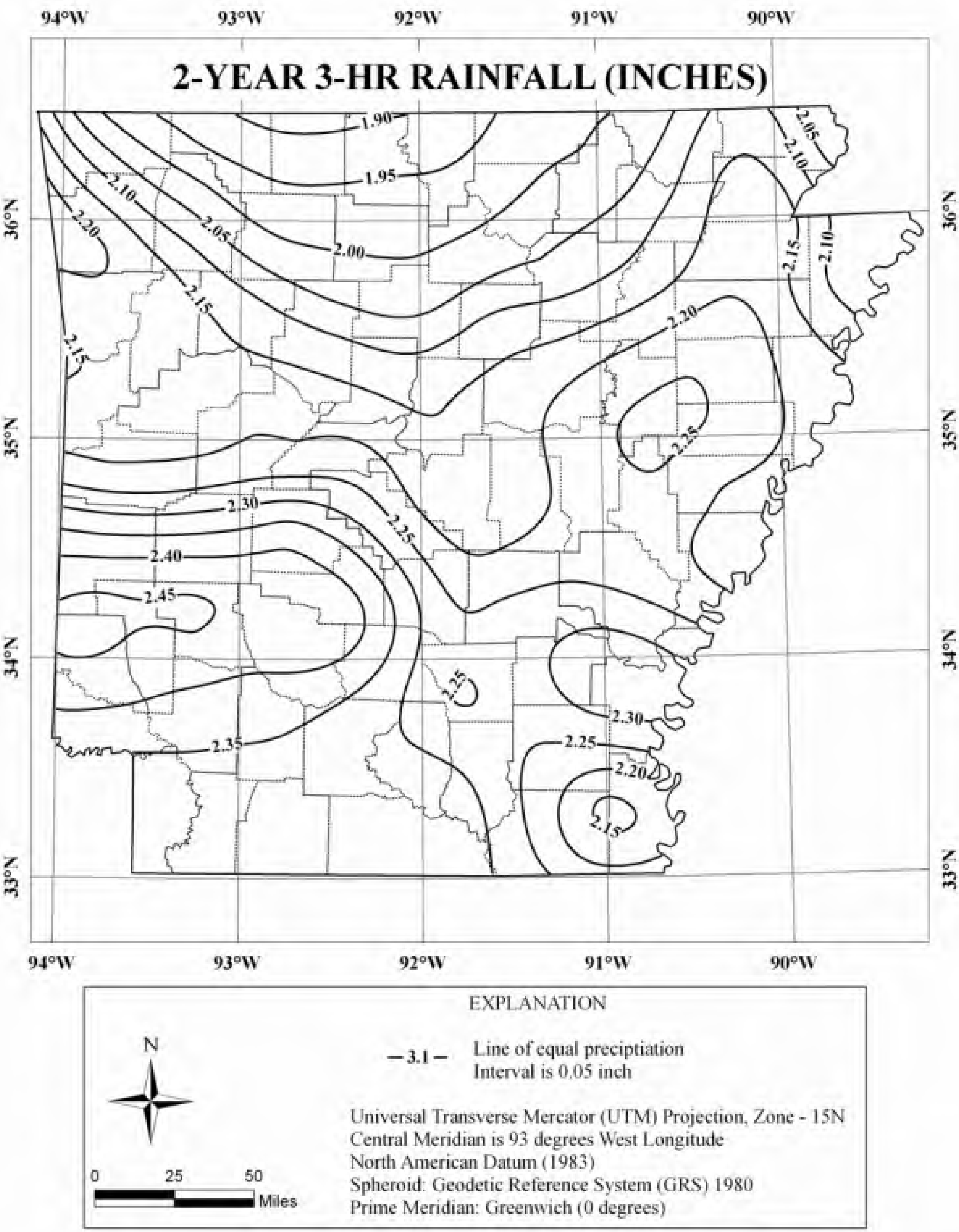

Figure 36. Depth of 2-year storm for 3-hour interval in Arkansas.

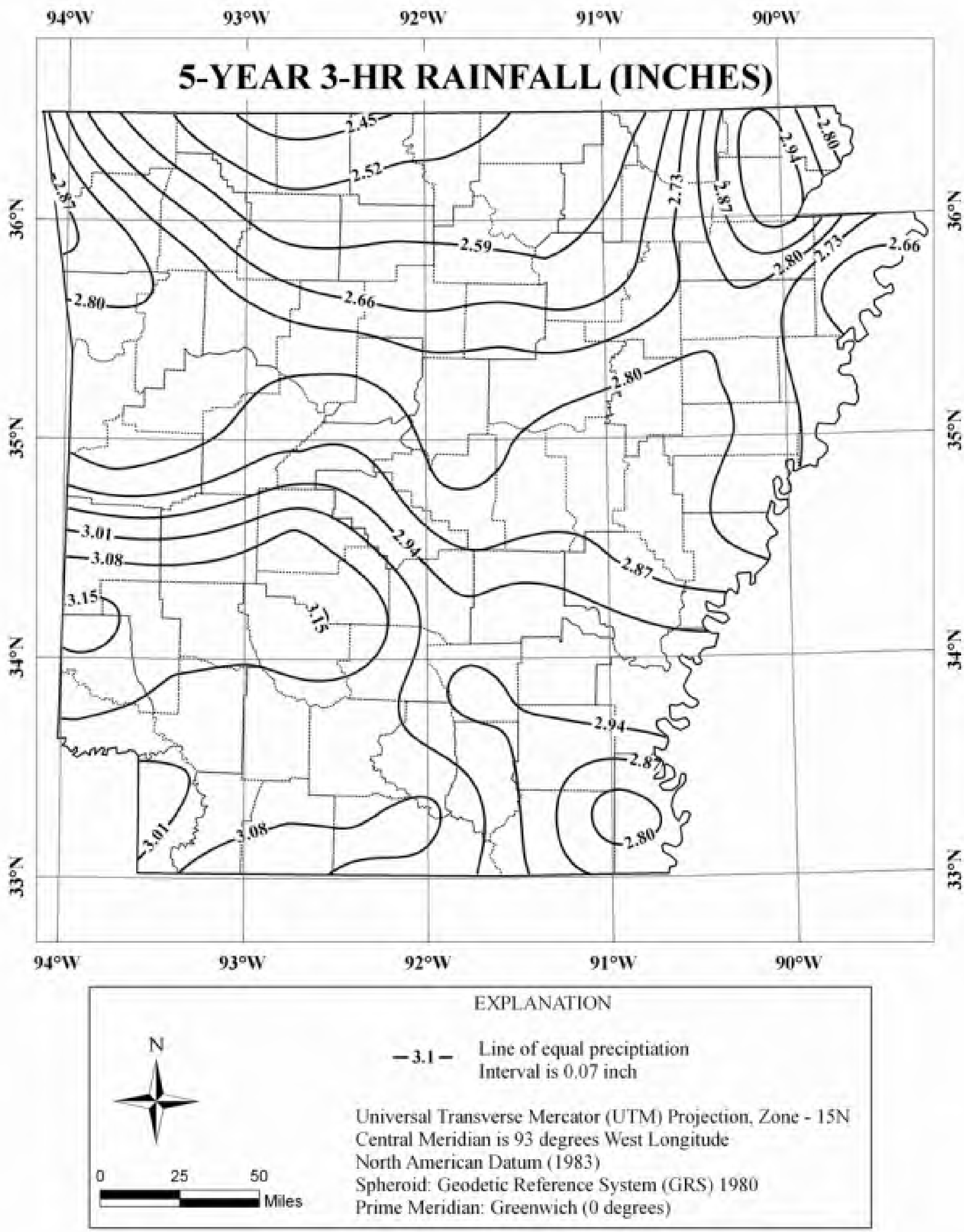

Figure 37. Depth of 5-year storm for 3-hour interval in Arkansas.

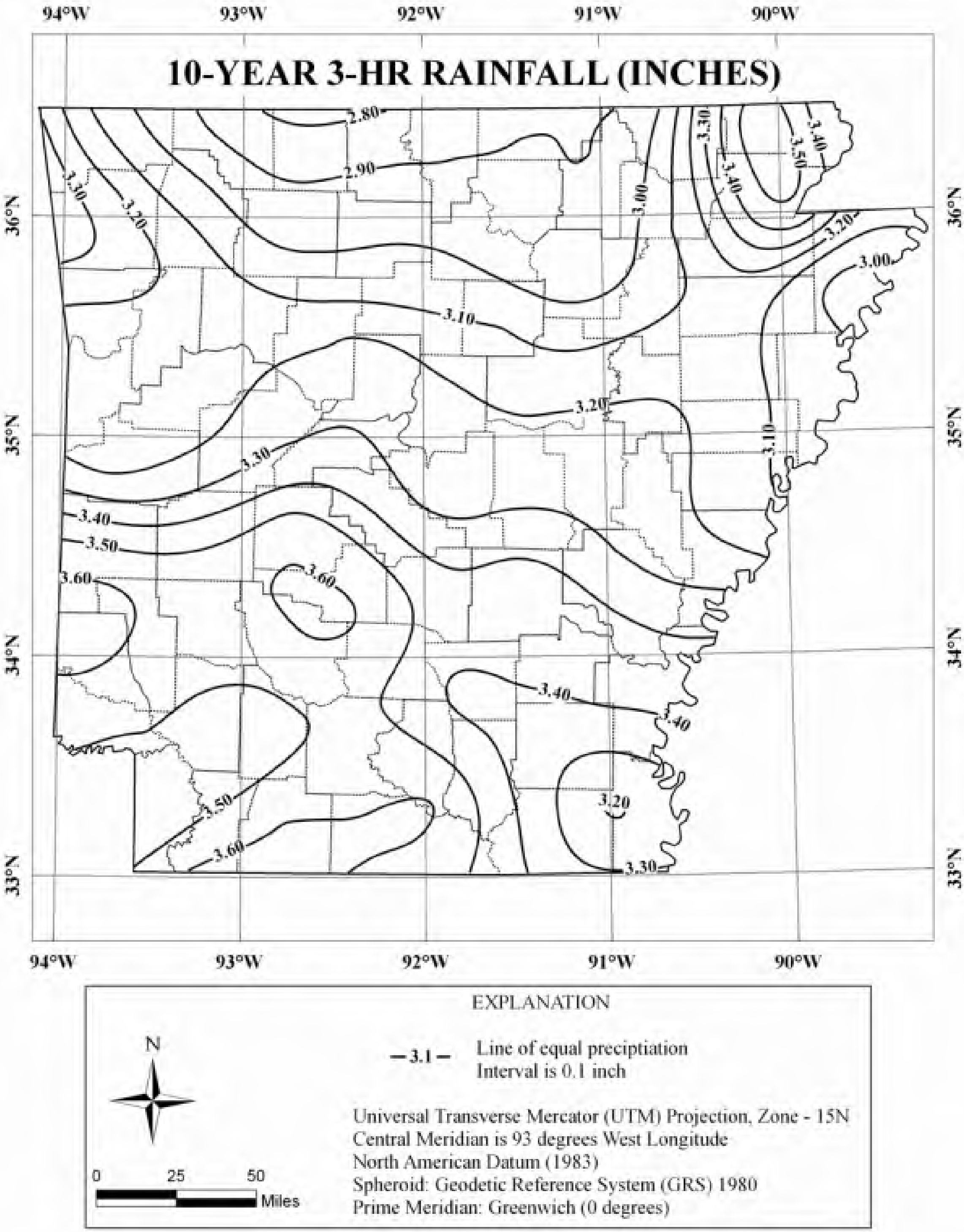

Figure 38. Depth of 10-year storm for 3-hour interval in Arkansas.

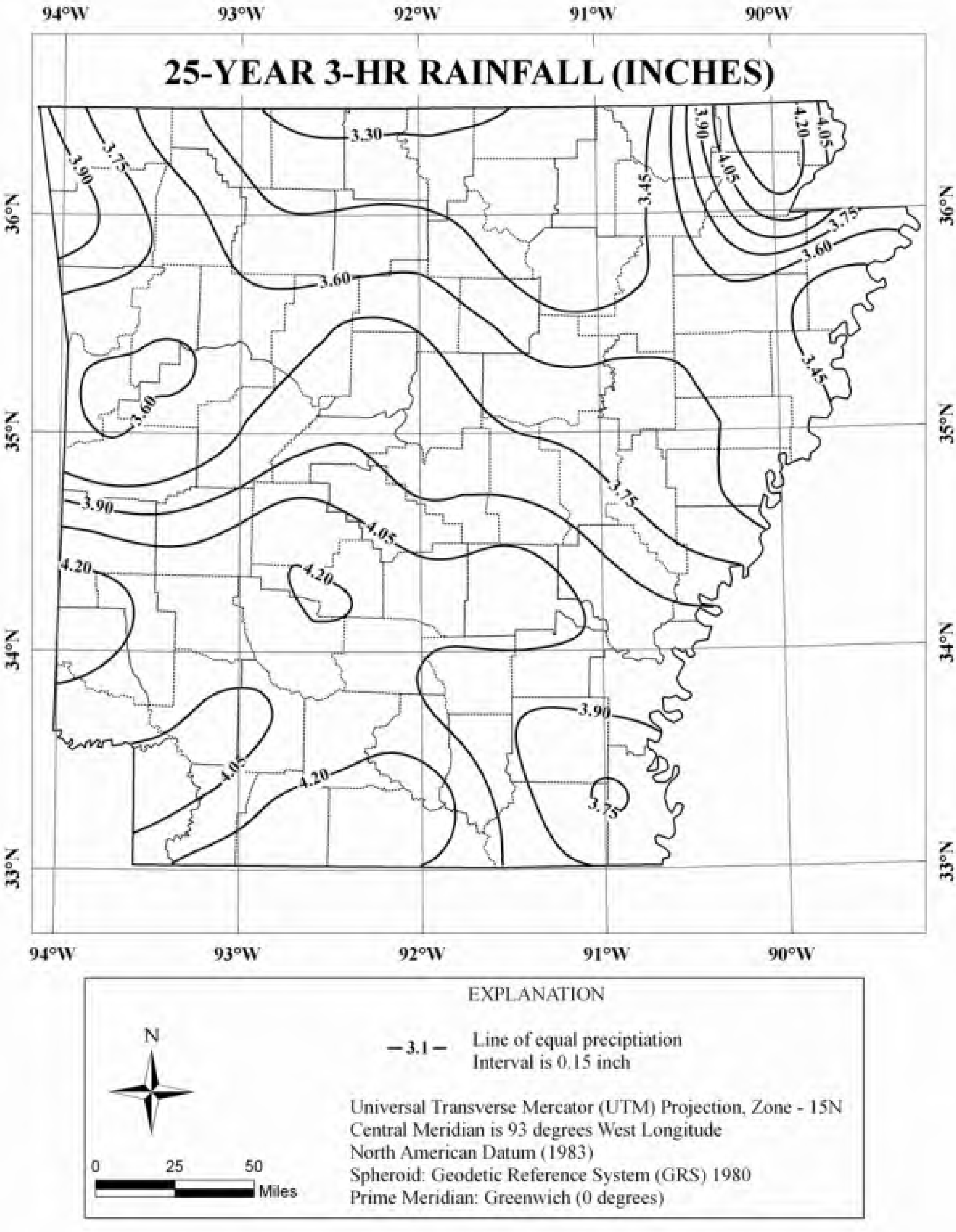

Figure 39. Depth of 25-year storm for 3-hour interval in Arkansas.

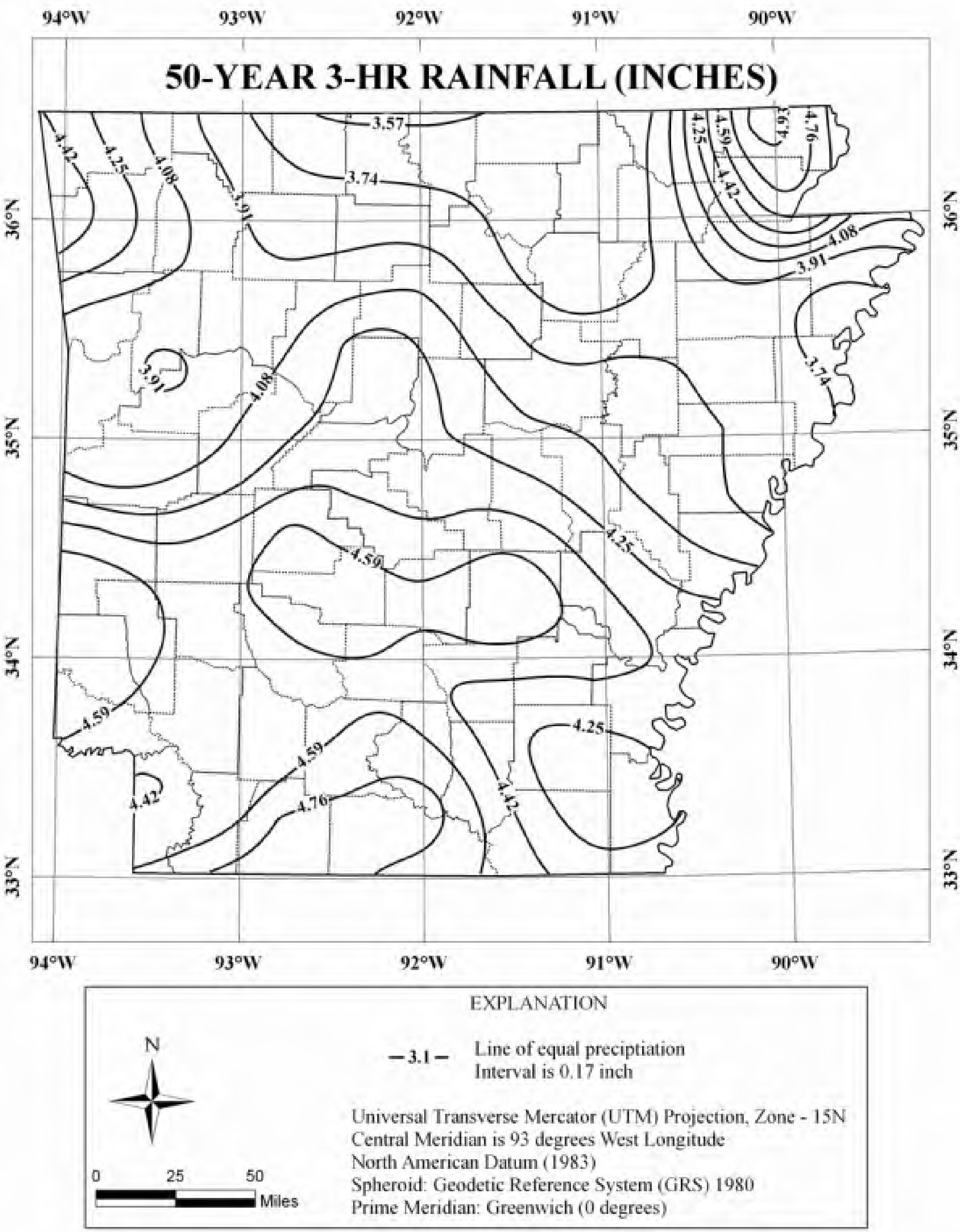

Figure 40. Depth of 50-year storm for 3-hour interval in Arkansas.

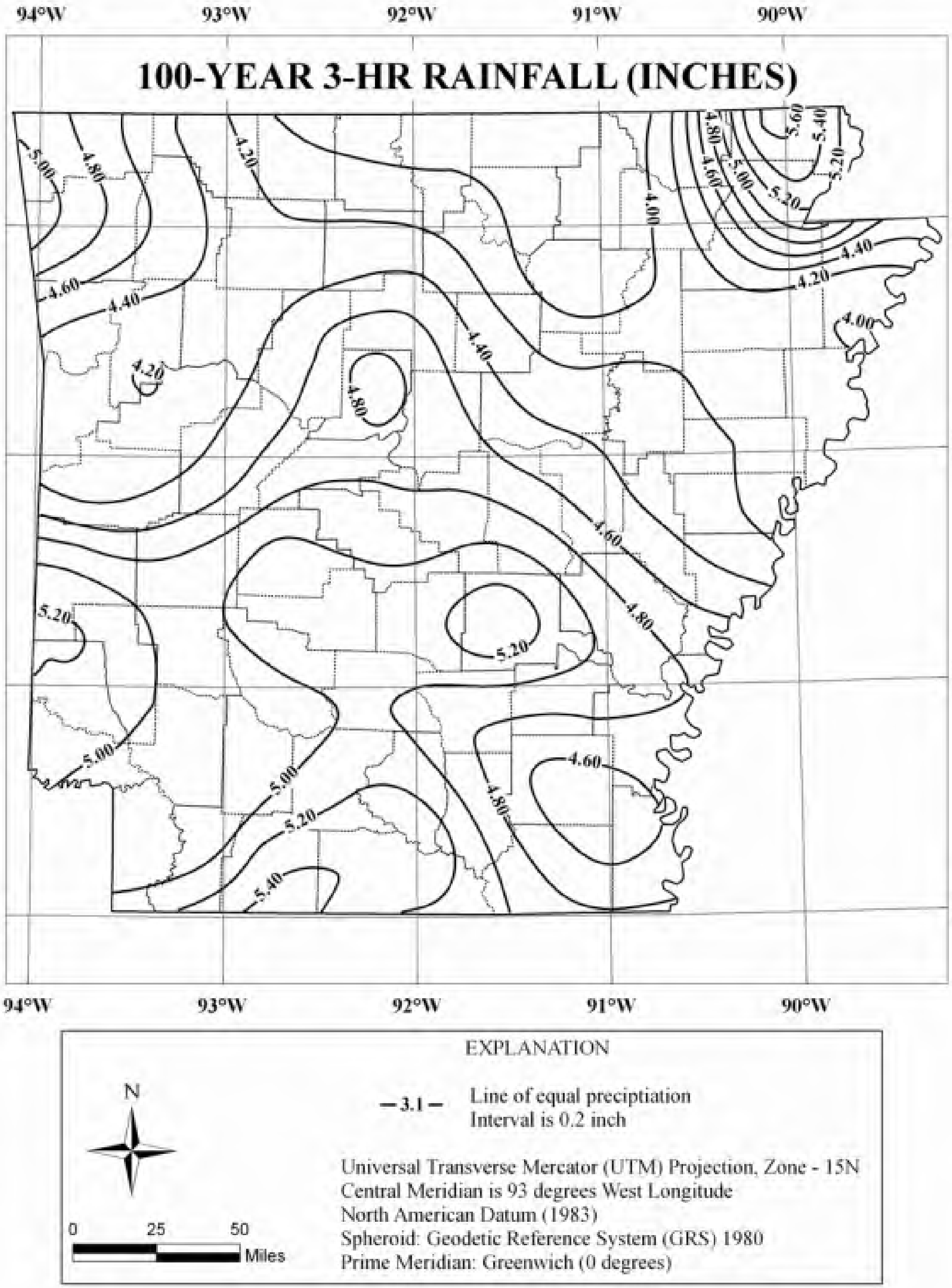

Figure 41. Depth of 100-year storm for 3-hour interval in Arkansas.

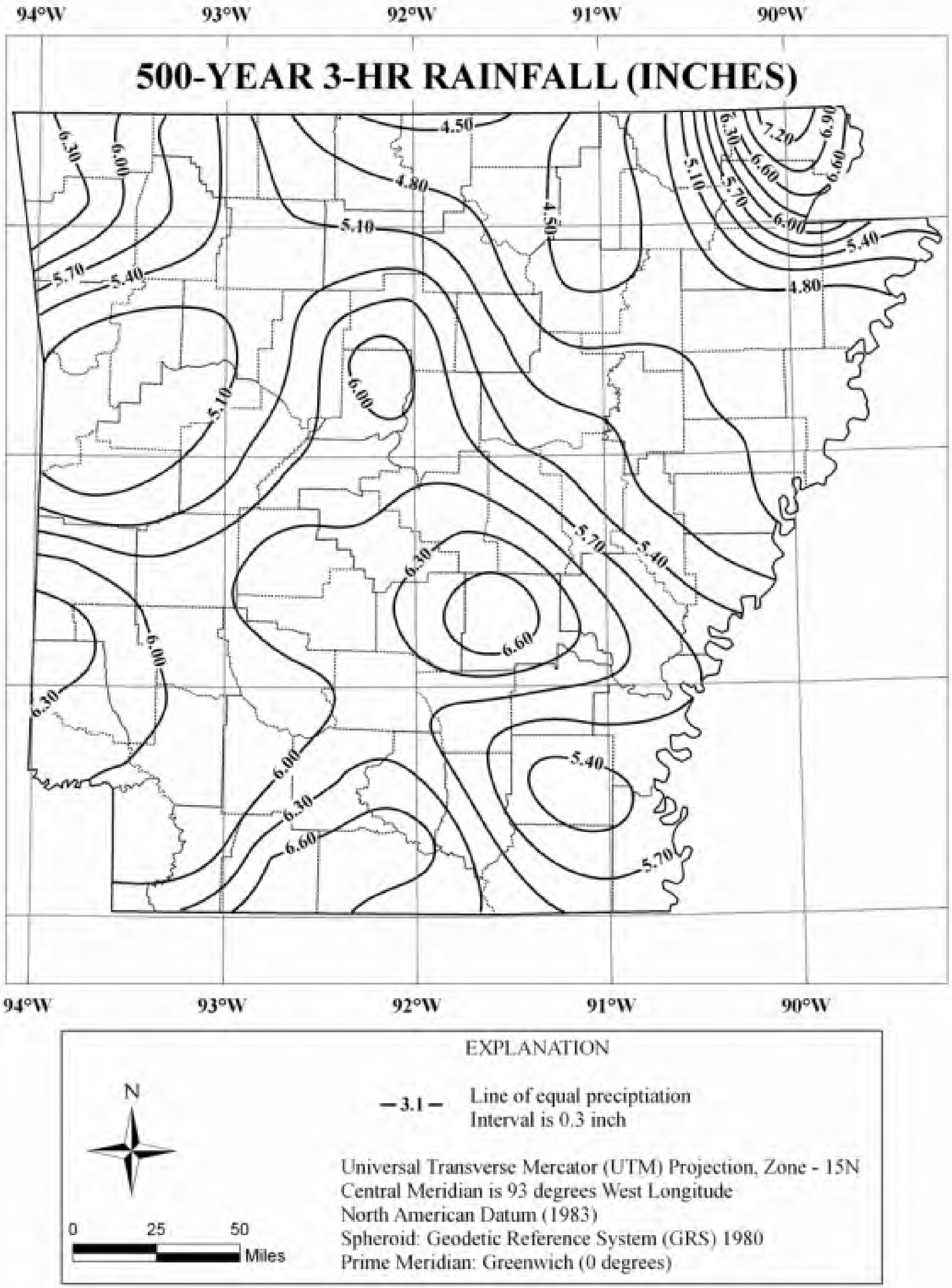

Figure 42. Depth of 500-year storm for 3-hour interval in Arkansas.

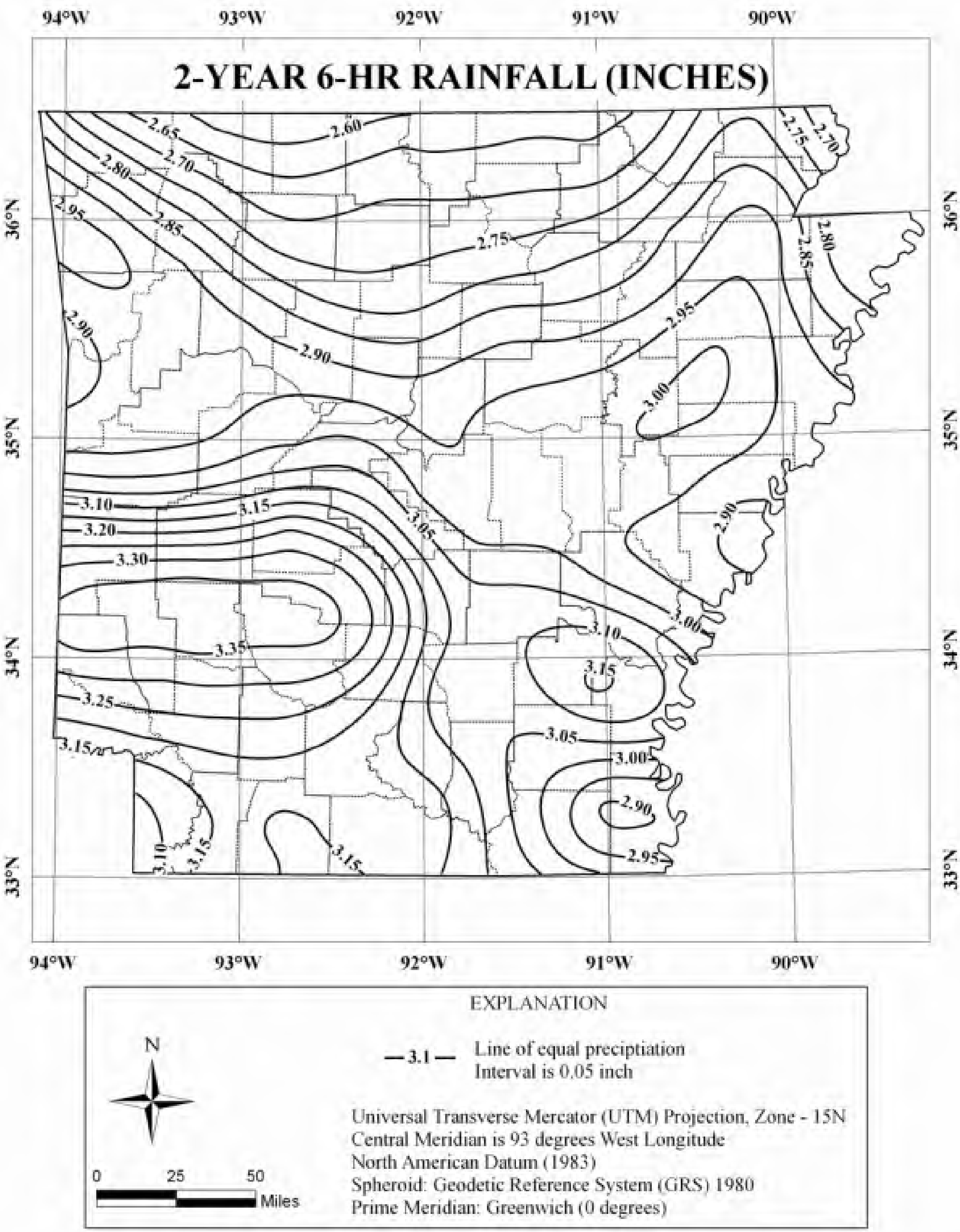

Figure 43. Depth of 2-year storm for 6-hour interval in Arkansas.

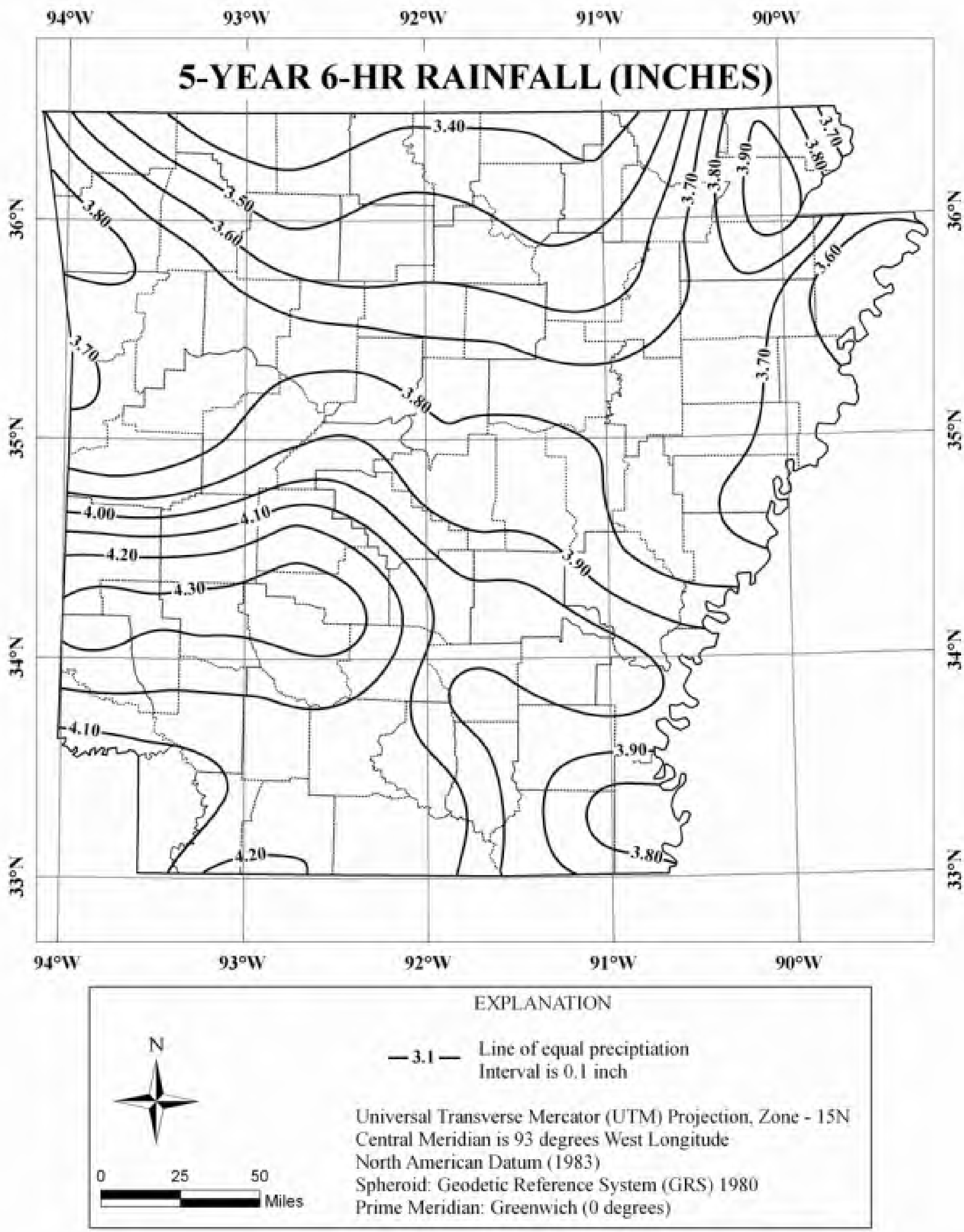

Figure 44. Depth of 5-year storm for 6-hour interval in Arkansas.

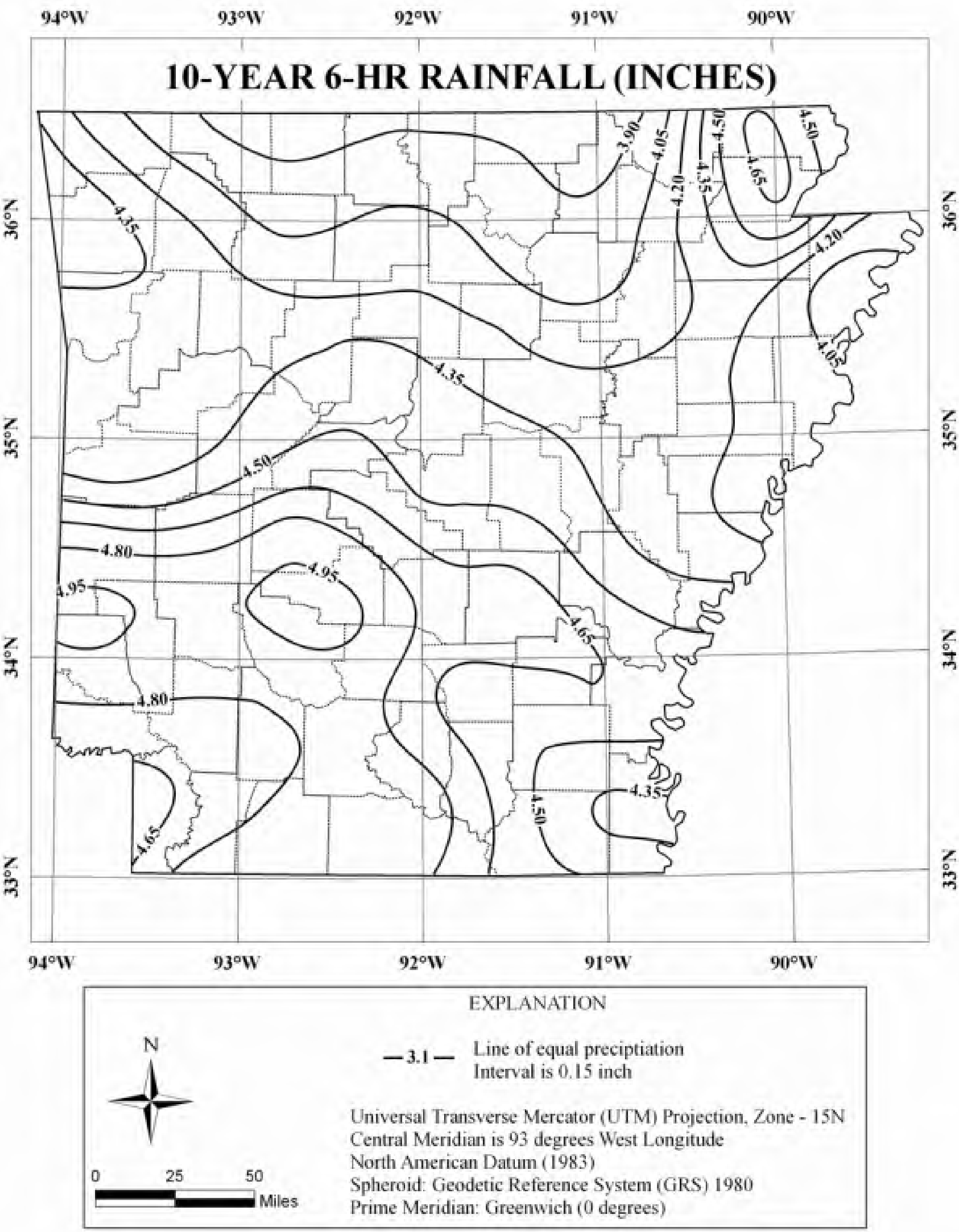

Figure 45. Depth of 10-year storm for 6-hour interval in Arkansas.

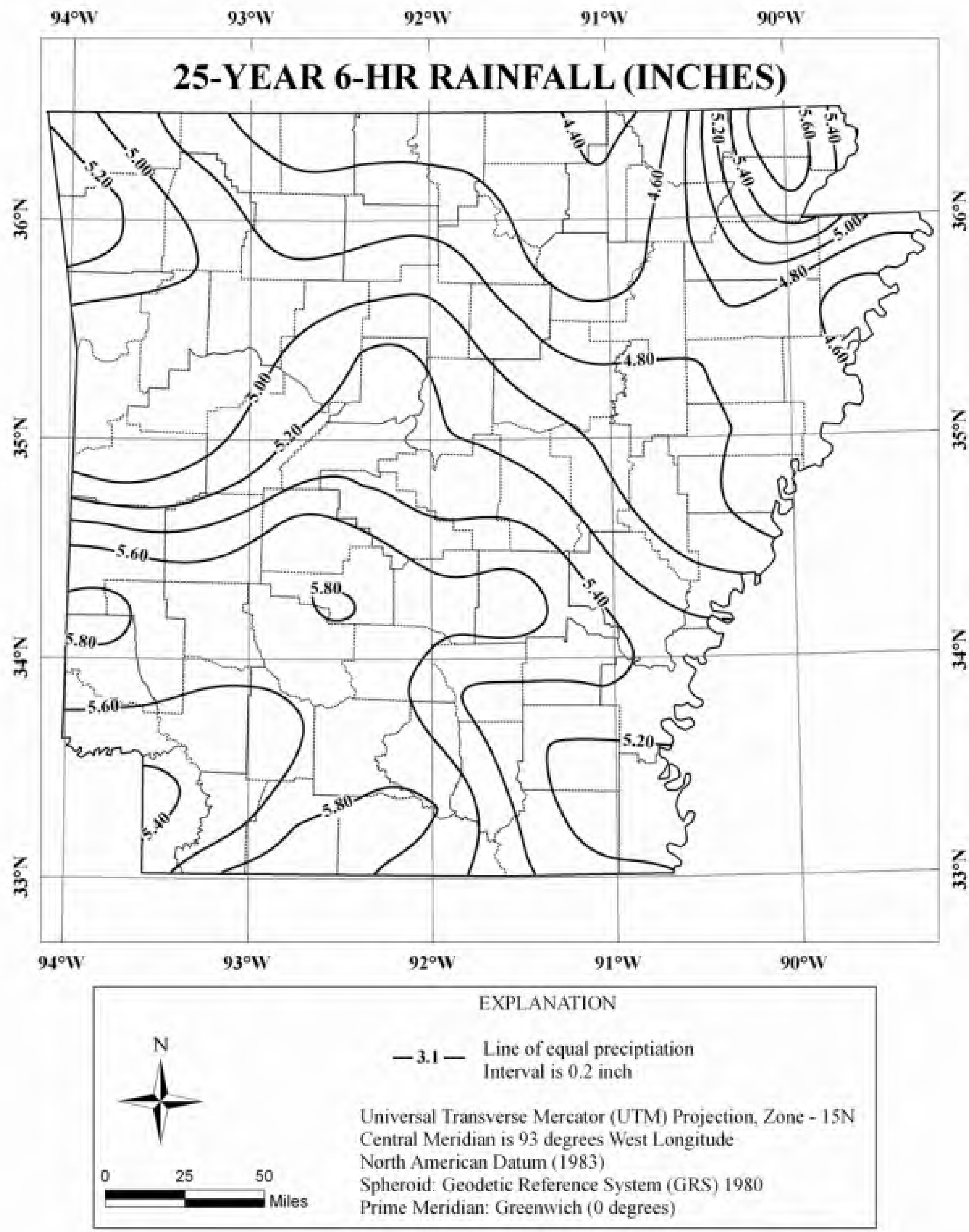

Figure 46. Depth of 25-year storm for 6-hour interval in Arkansas.

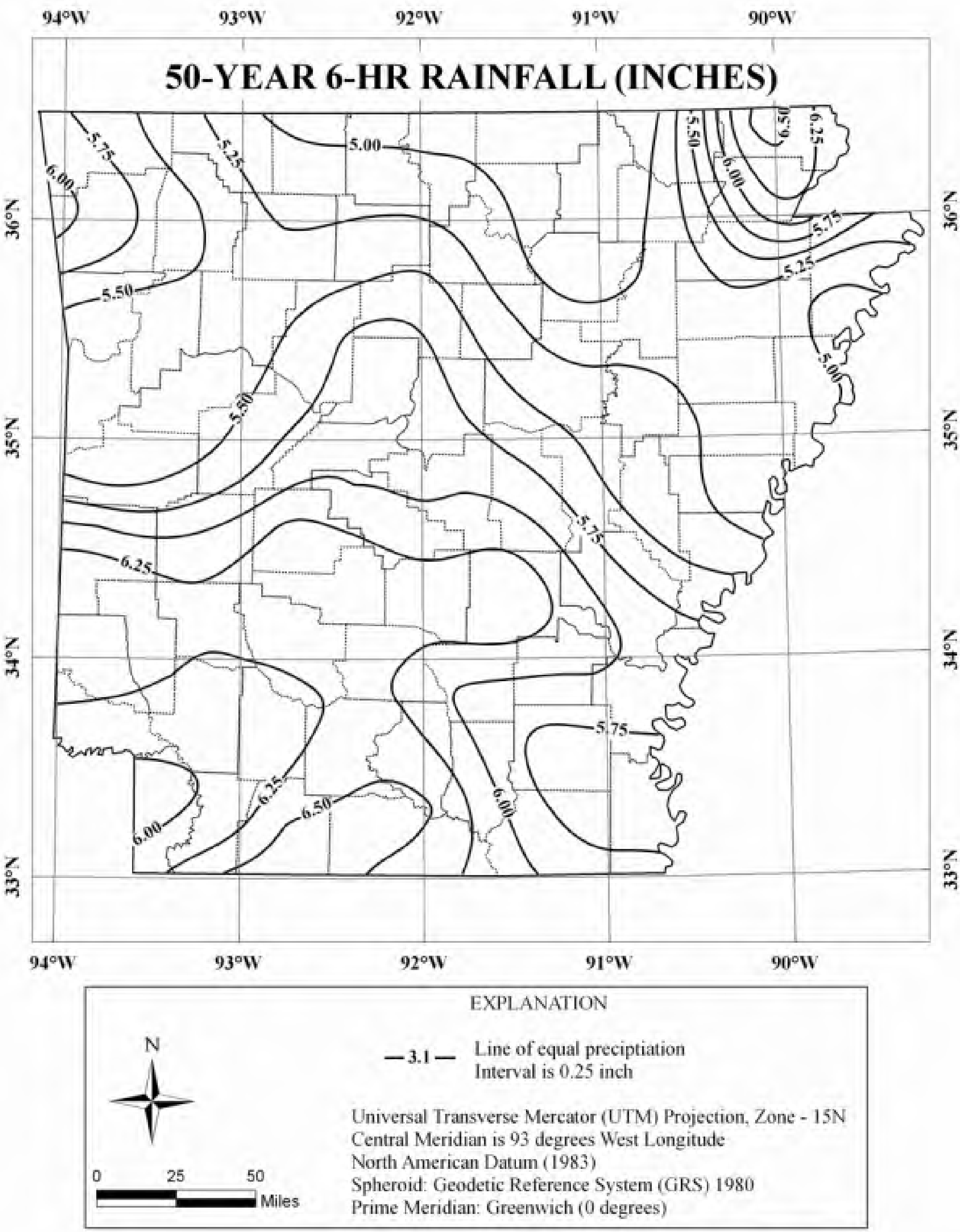

Figure 47. Depth of 50-year storm for 6-hour interval in Arkansas.

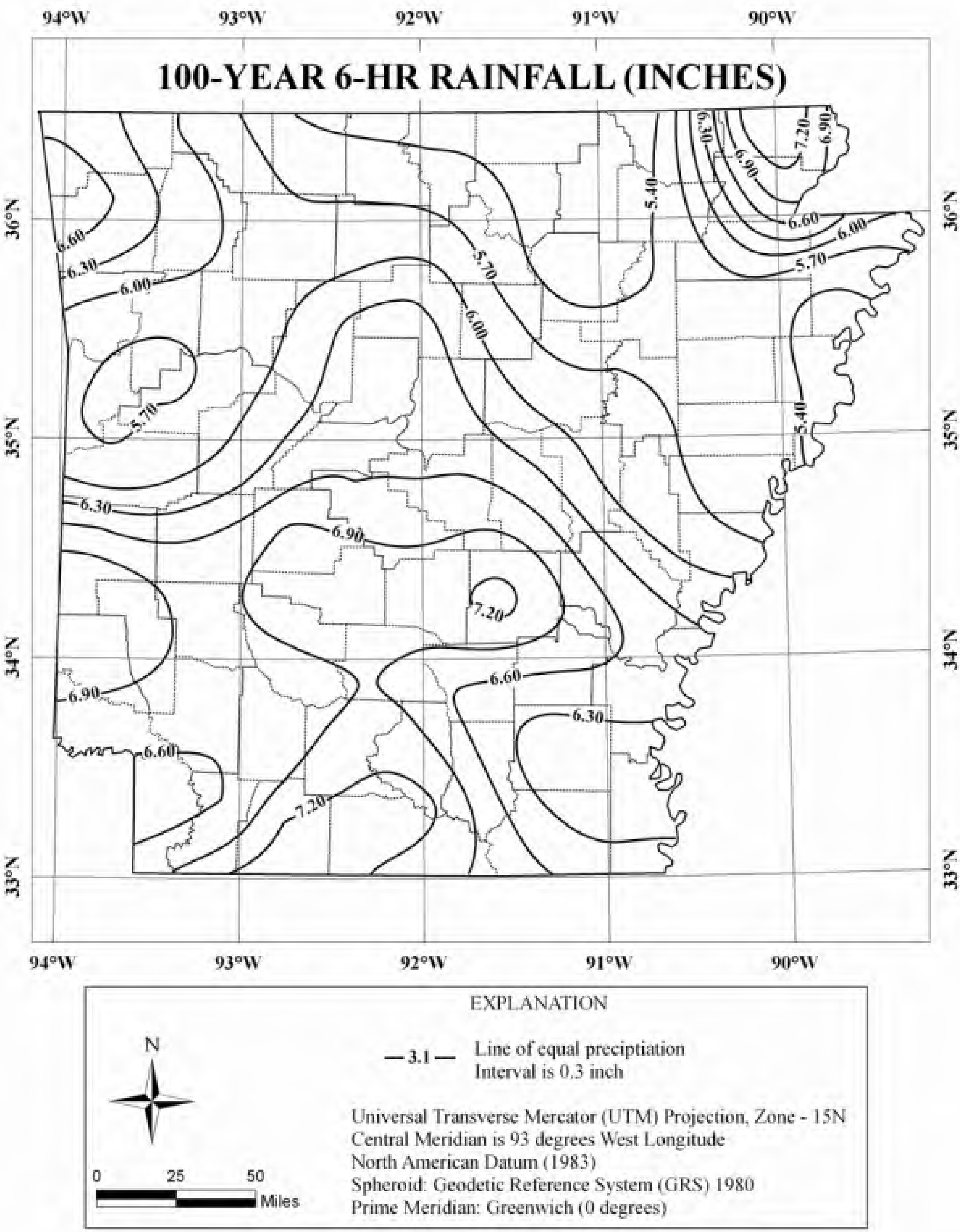

Figure 48. Depth of 100-year storm for 6-hour interval in Arkansas.

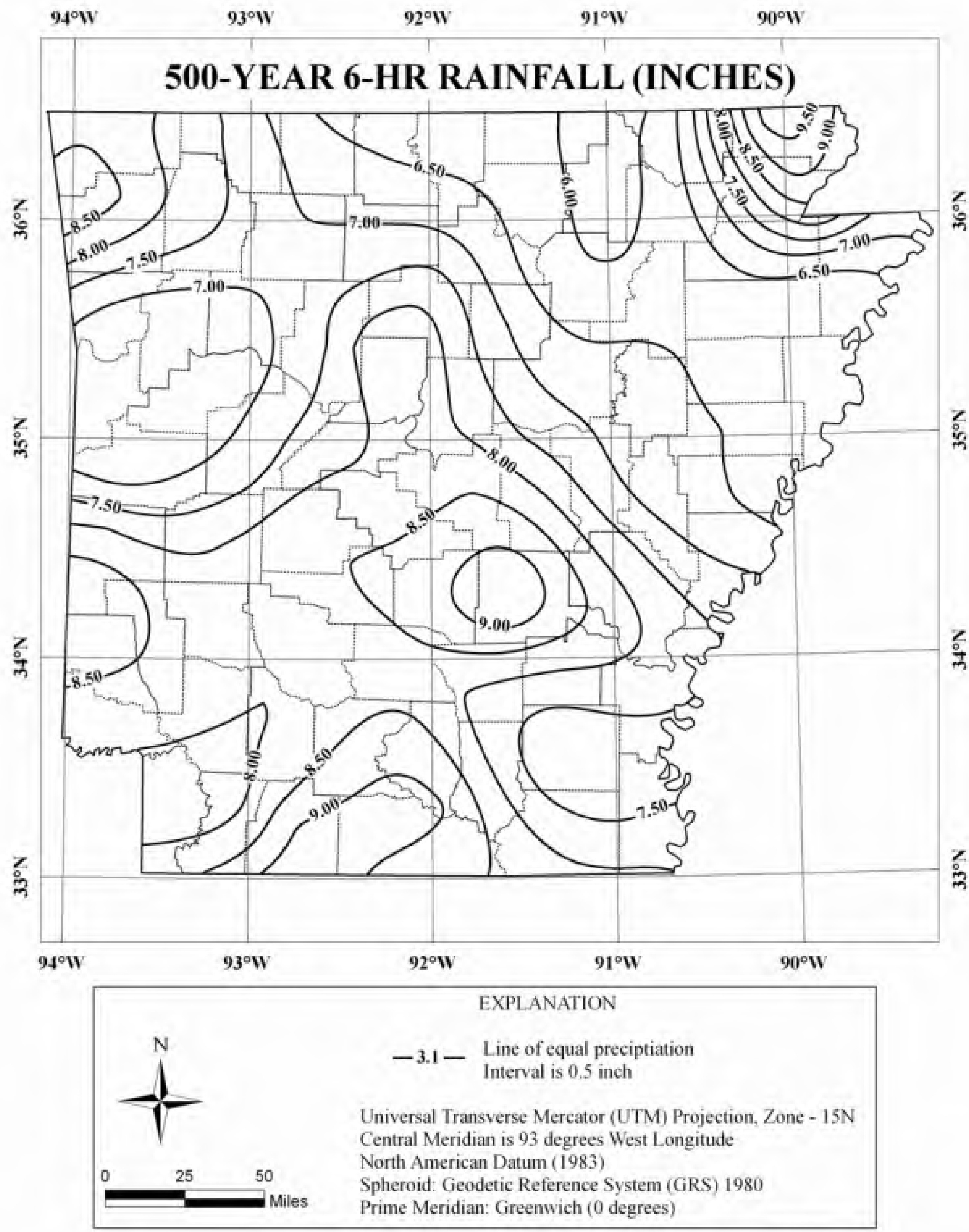

Figure 49. Depth of 500-year storm for 6-hour interval in Arkansas.

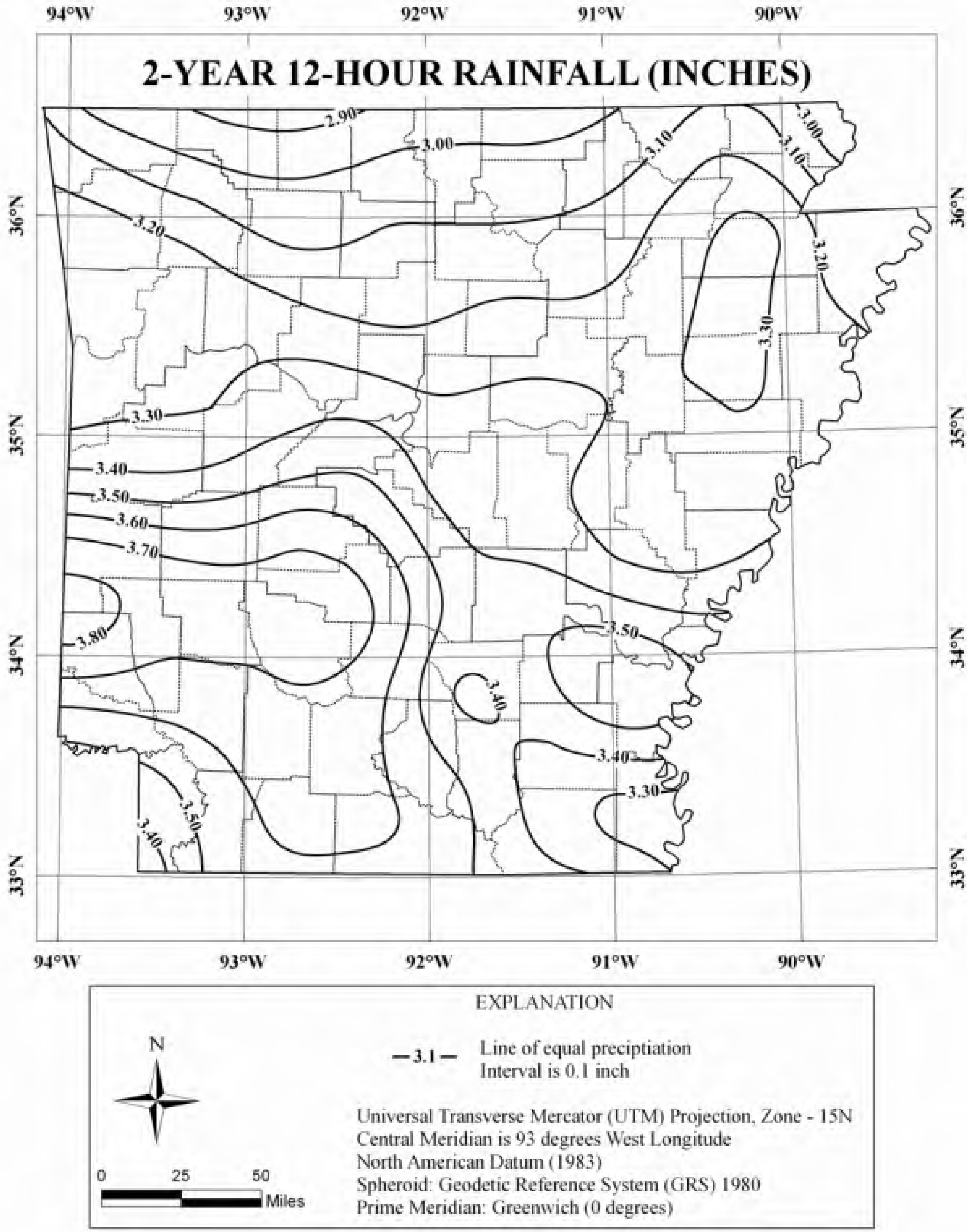

Figure 50. Depth of 2-year storm for 12-hour interval in Arkansas.

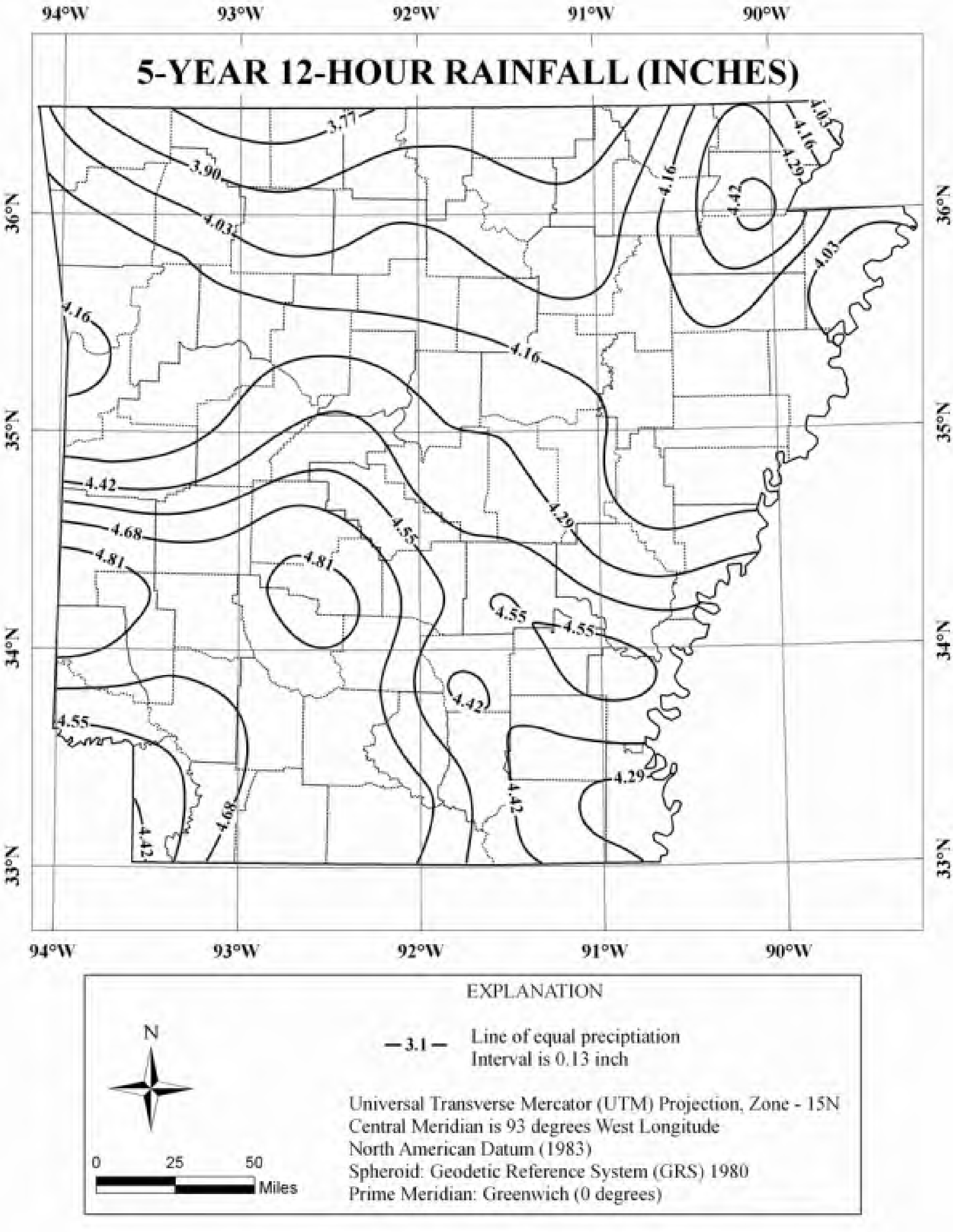

Figure 51. Depth of 5-year storm for 12-hour interval in Arkansas.

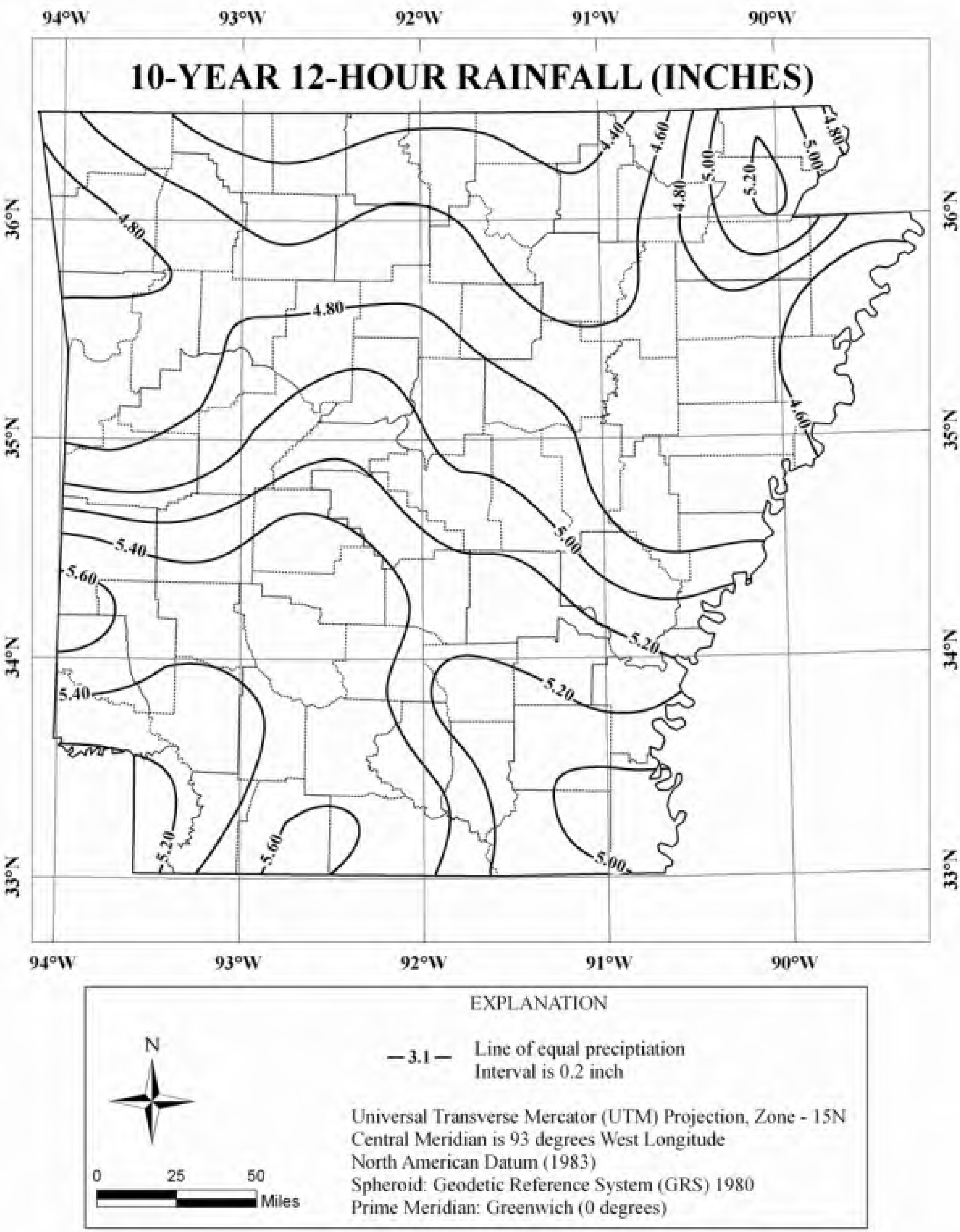

Figure 52. Depth of 10-year storm for 12-hour interval in Arkansas.

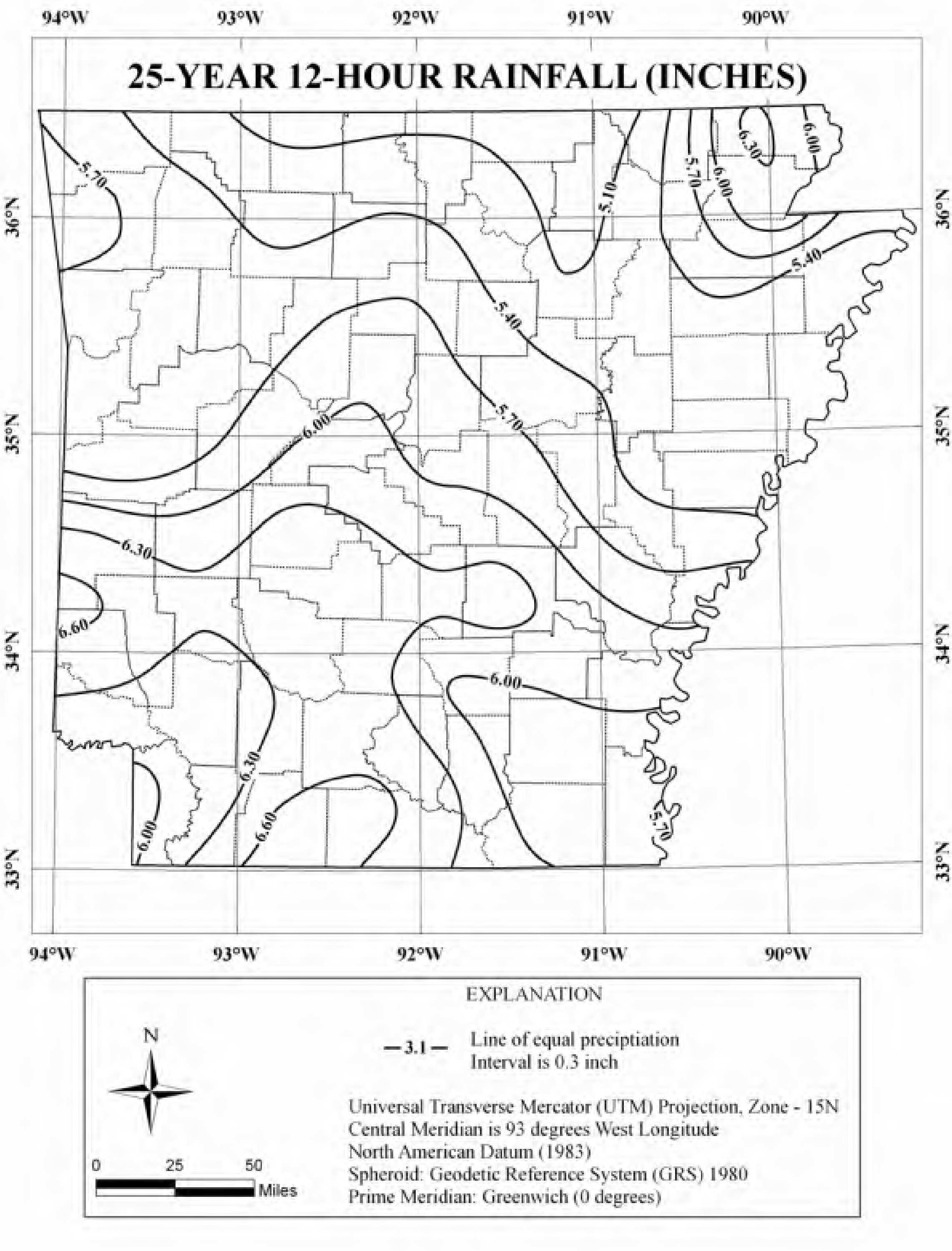

Figure 53. Depth of 25-year storm for 12-hour interval in Arkansas.

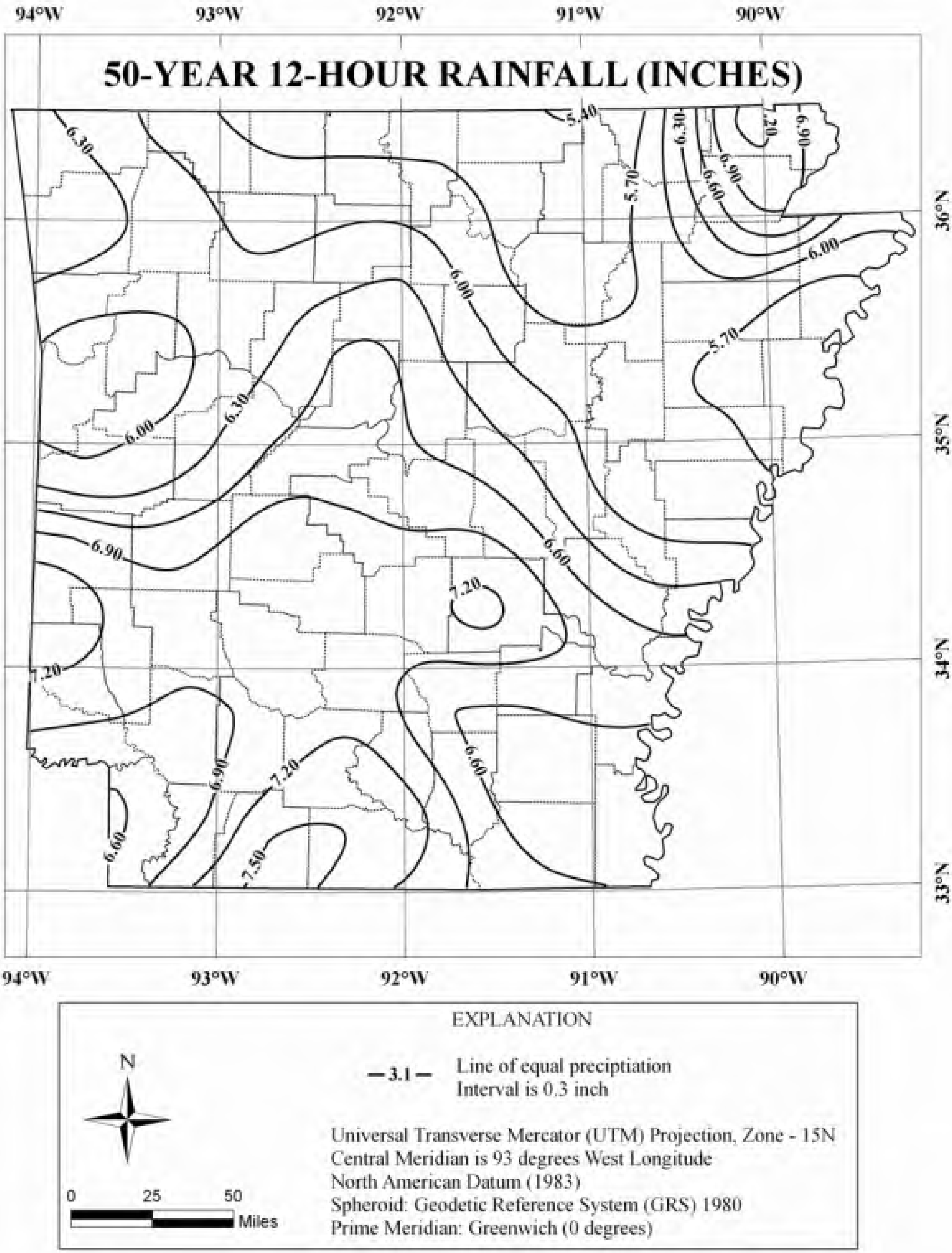

Figure 54. Depth of 50-year storm for 12-hour interval in Arkansas.

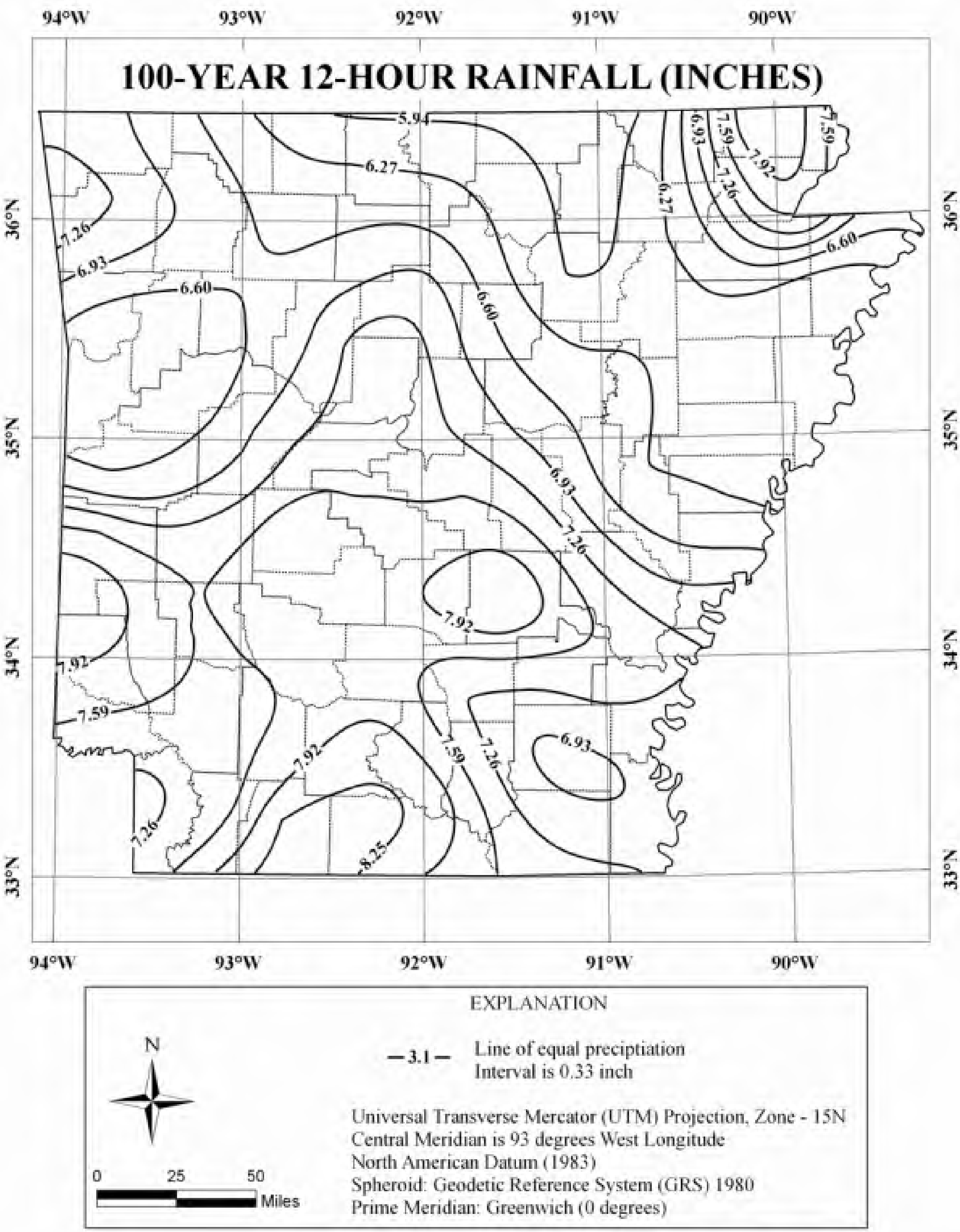

Figure 55. Depth of 100-year storm for 12-hour interval in Arkansas.

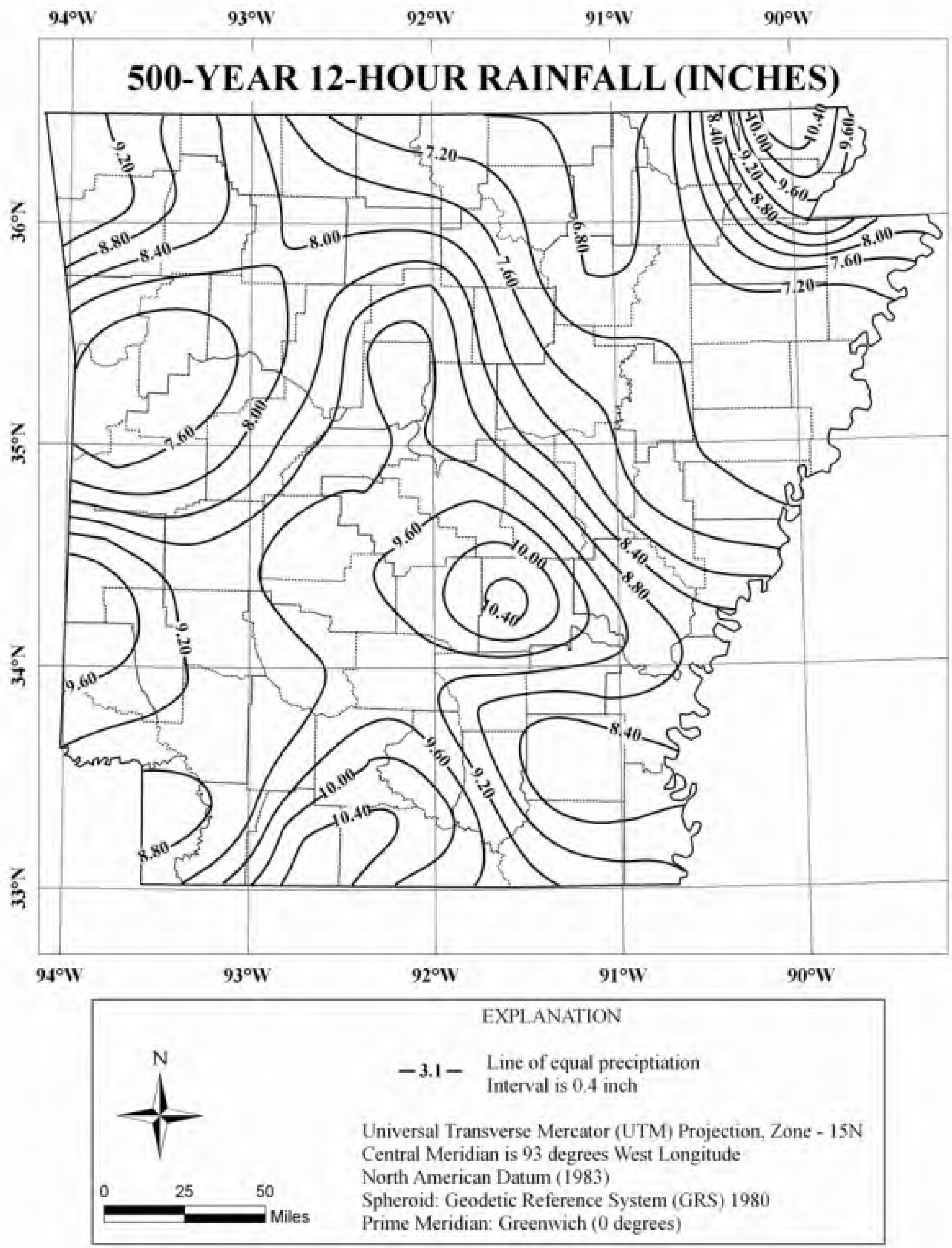

Figure 56. Depth of 500-year storm for 12-hour interval in Arkansas.

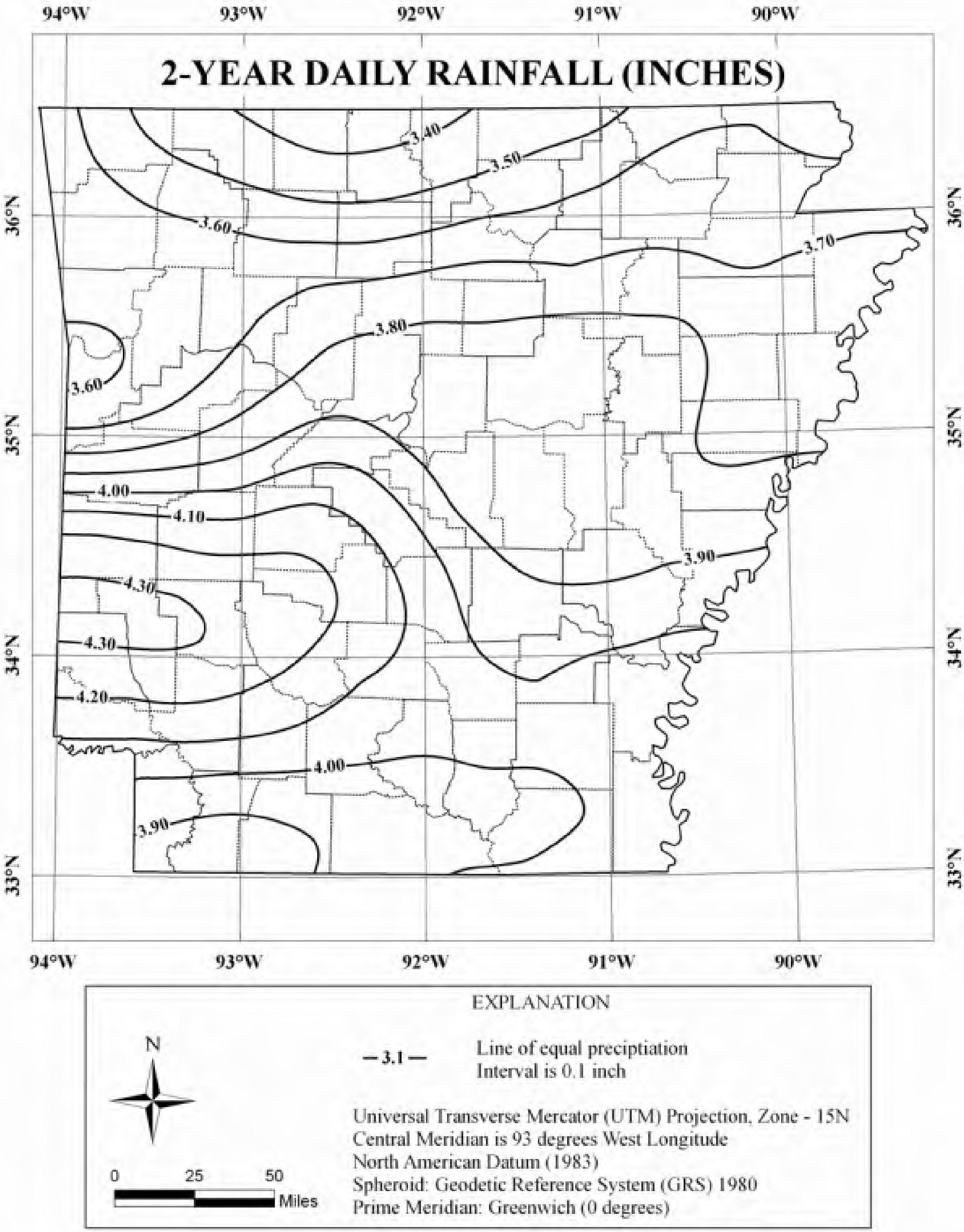

Figure 57. Depth of 2-year storm for 1-day interval in Arkansas.

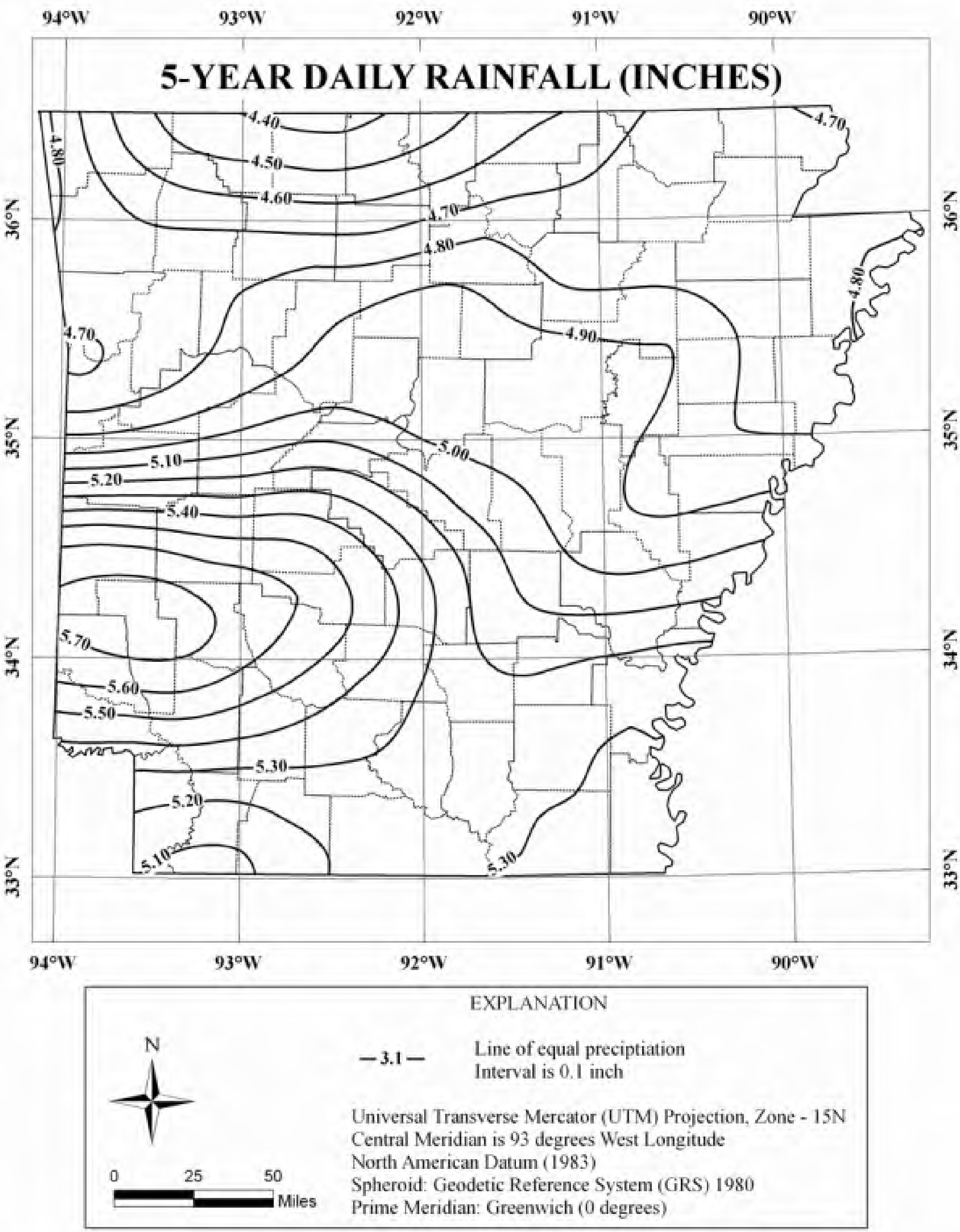

Figure 58. Depth of 5-year storm for 1-day interval in Arkansas.

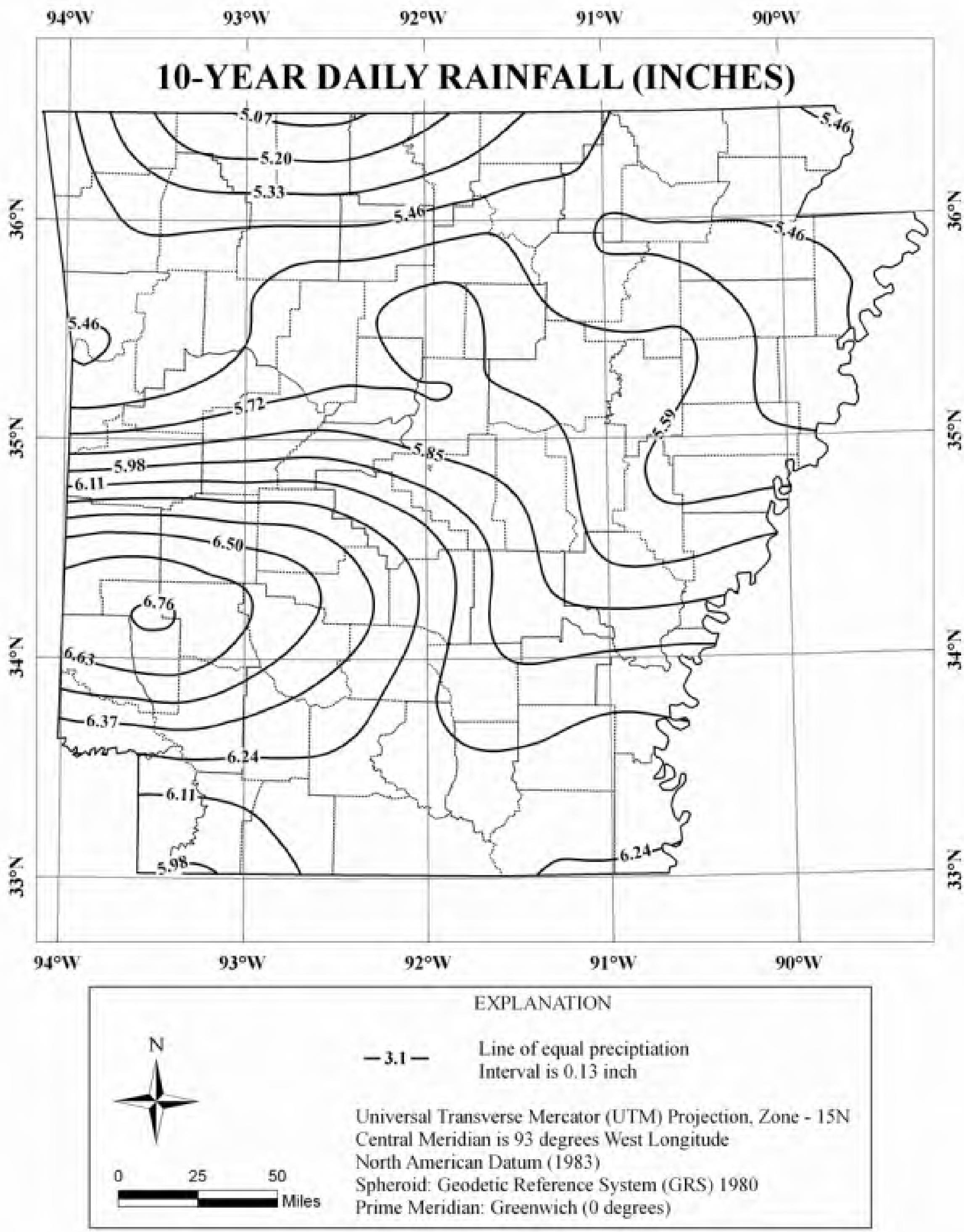

Figure 59. Depth of 10-year storm for 1-day interval in Arkansas.

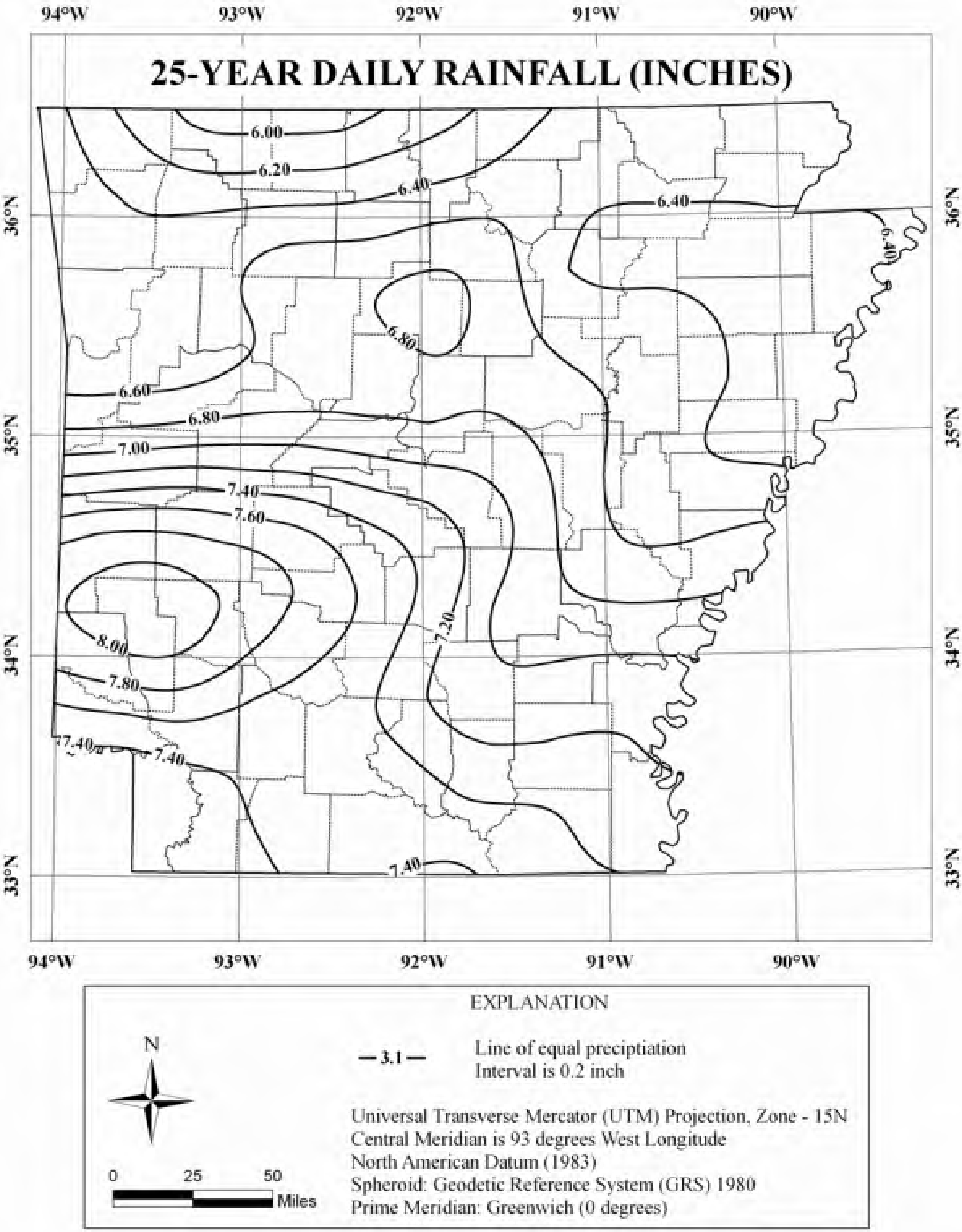

Figure 60. Depth of 25-year storm for 1-day interval in Arkansas.

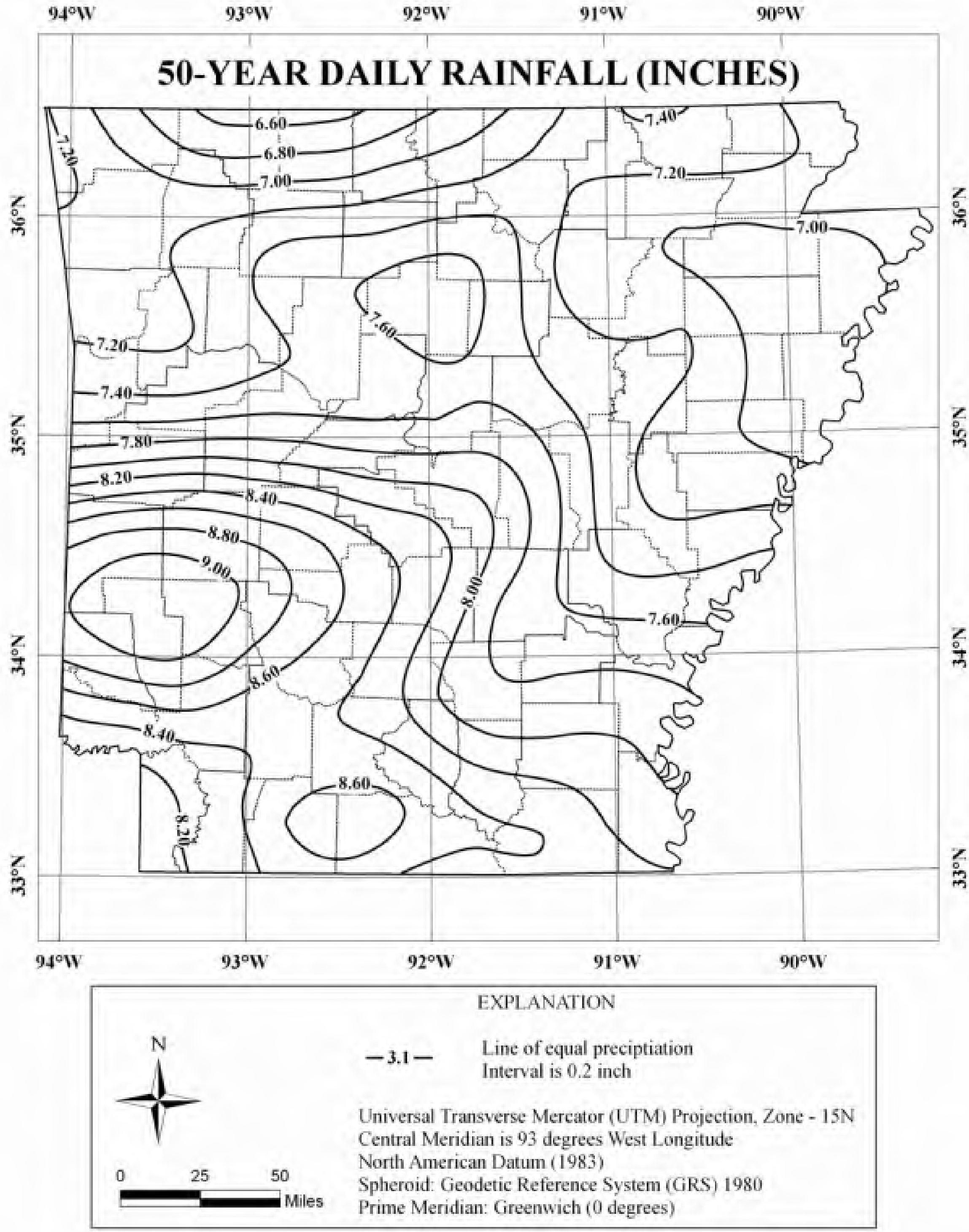

Figure 61. Depth of 50-year storm for 1-day interval in Arkansas.

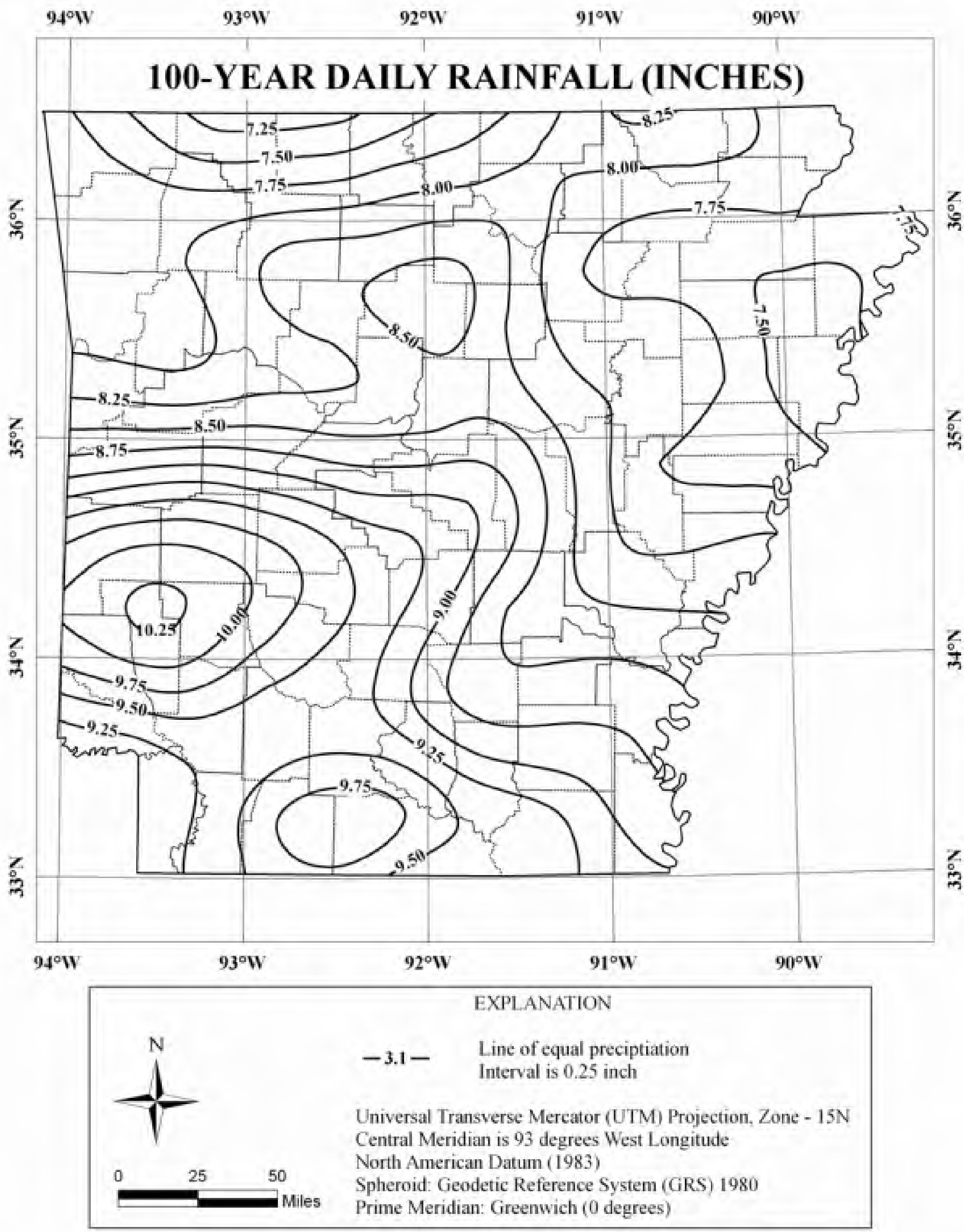

Figure 62. Depth of 100-year storm for 1-day interval in Arkansas.

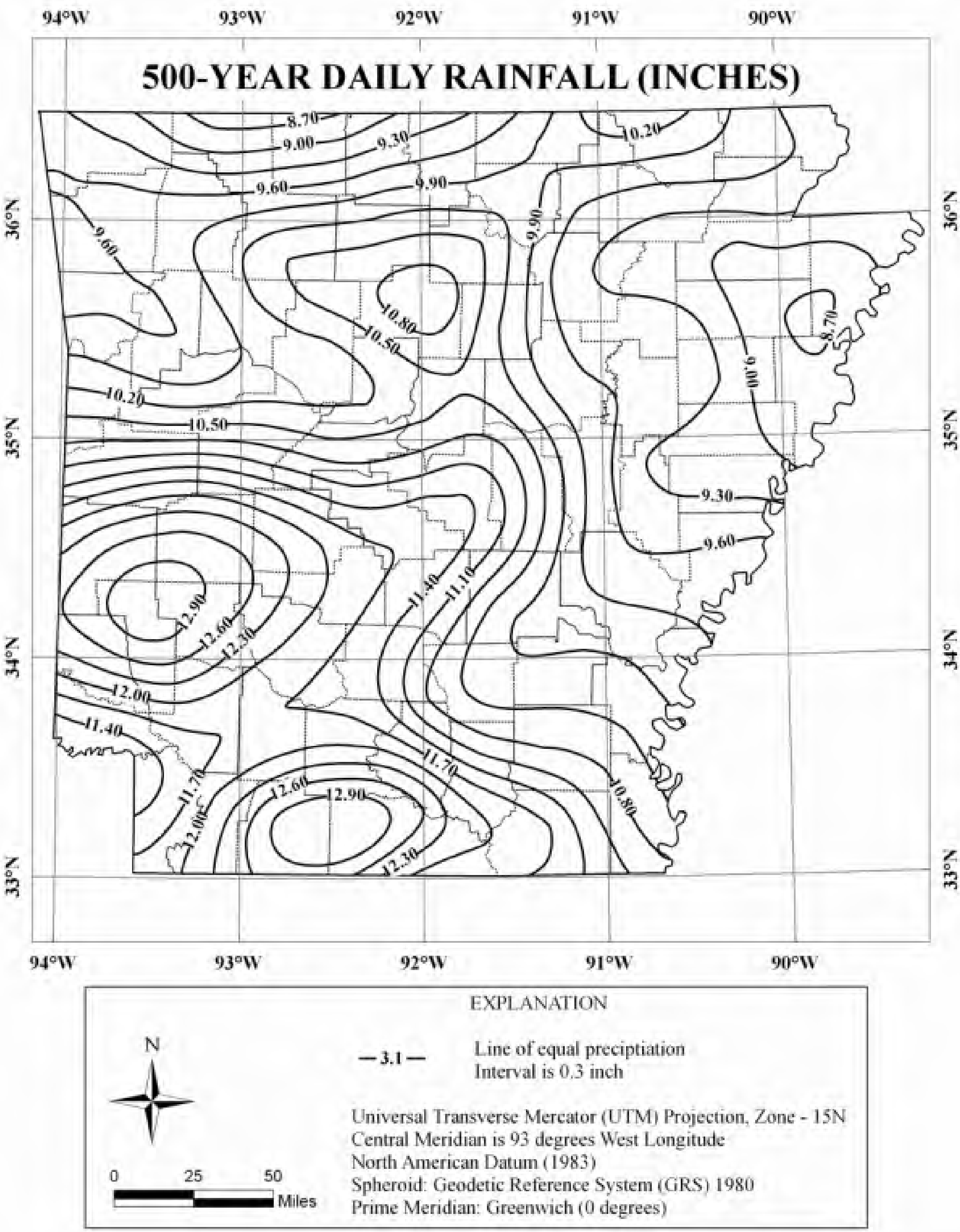

Figure 63. Depth of 500-year storm for 1-day interval in Arkansas.

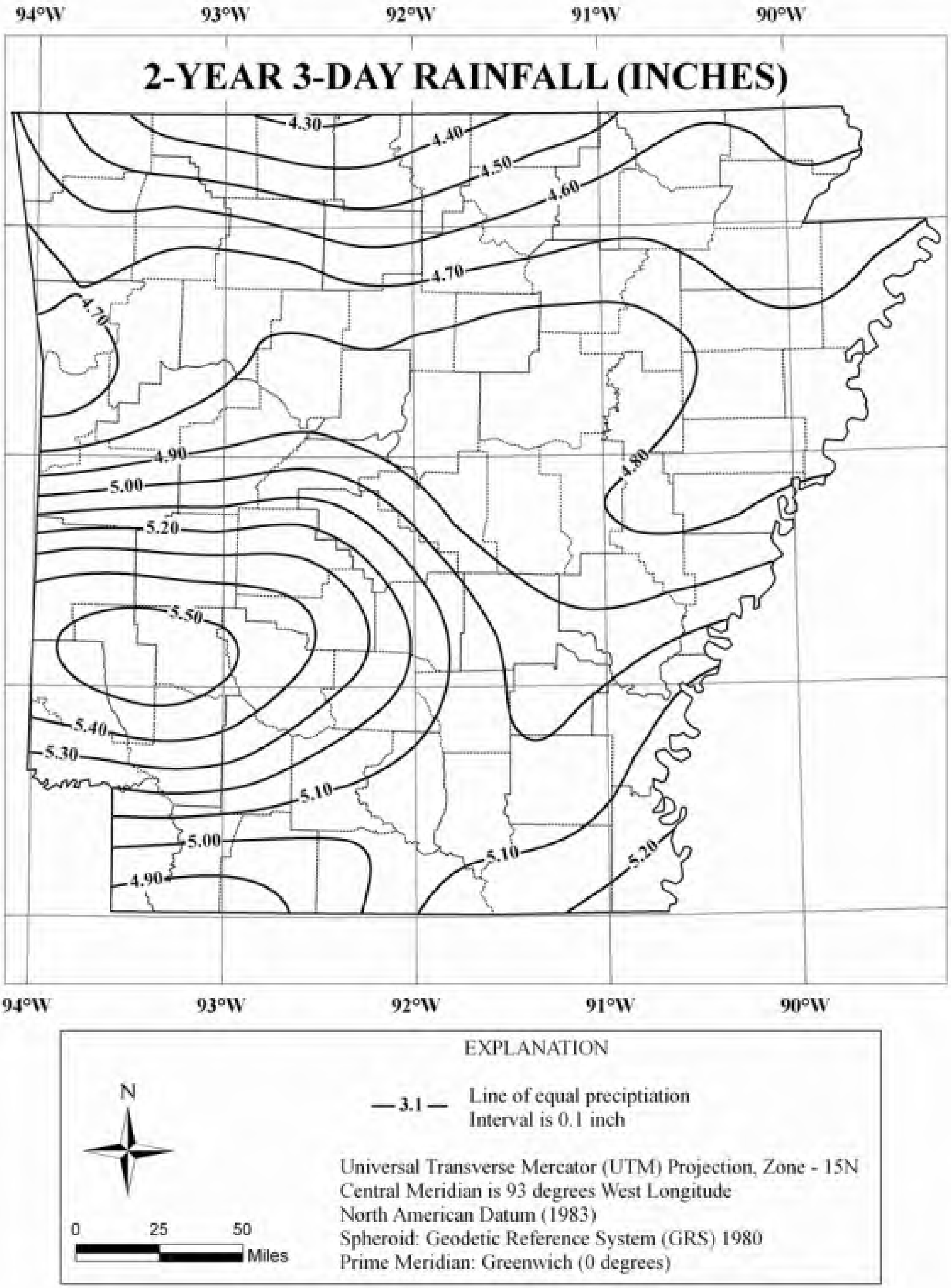

Figure 64. Depth of 2-year storm for 3-day interval in Arkansas.

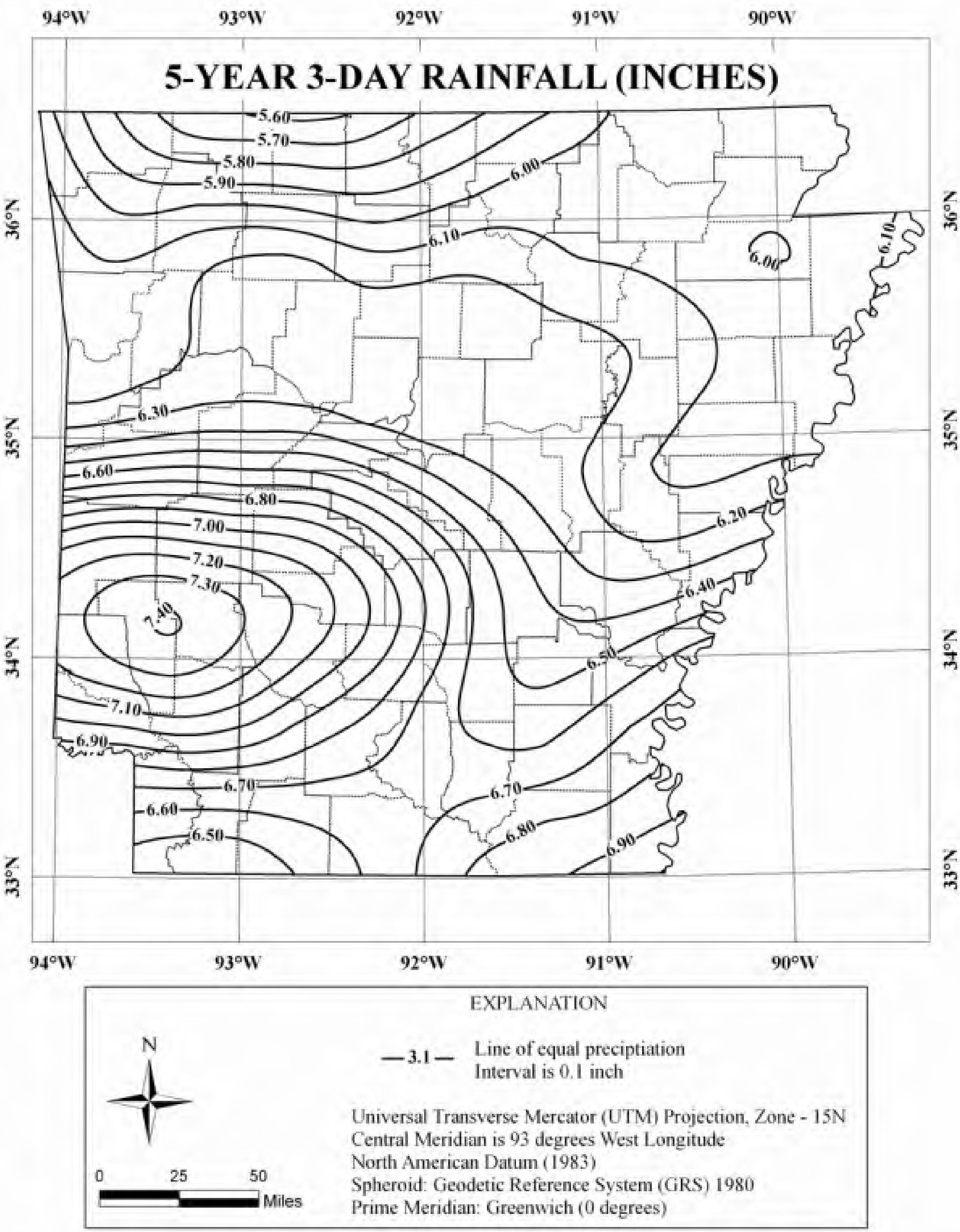

Figure 65. Depth of 5-year storm for 3-day interval in Arkansas.

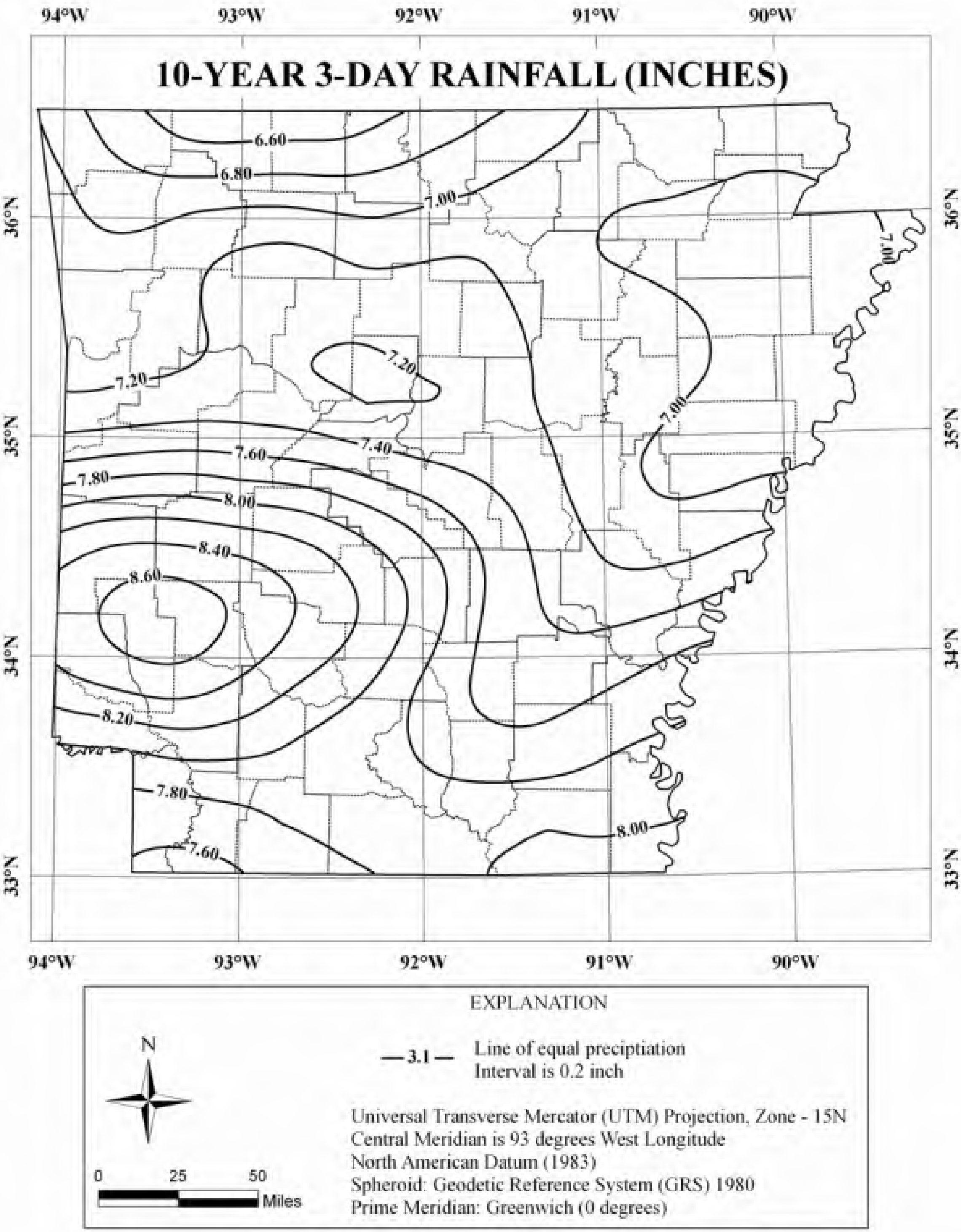

Figure 66. Depth of 10-year storm for 3-day interval in Arkansas.

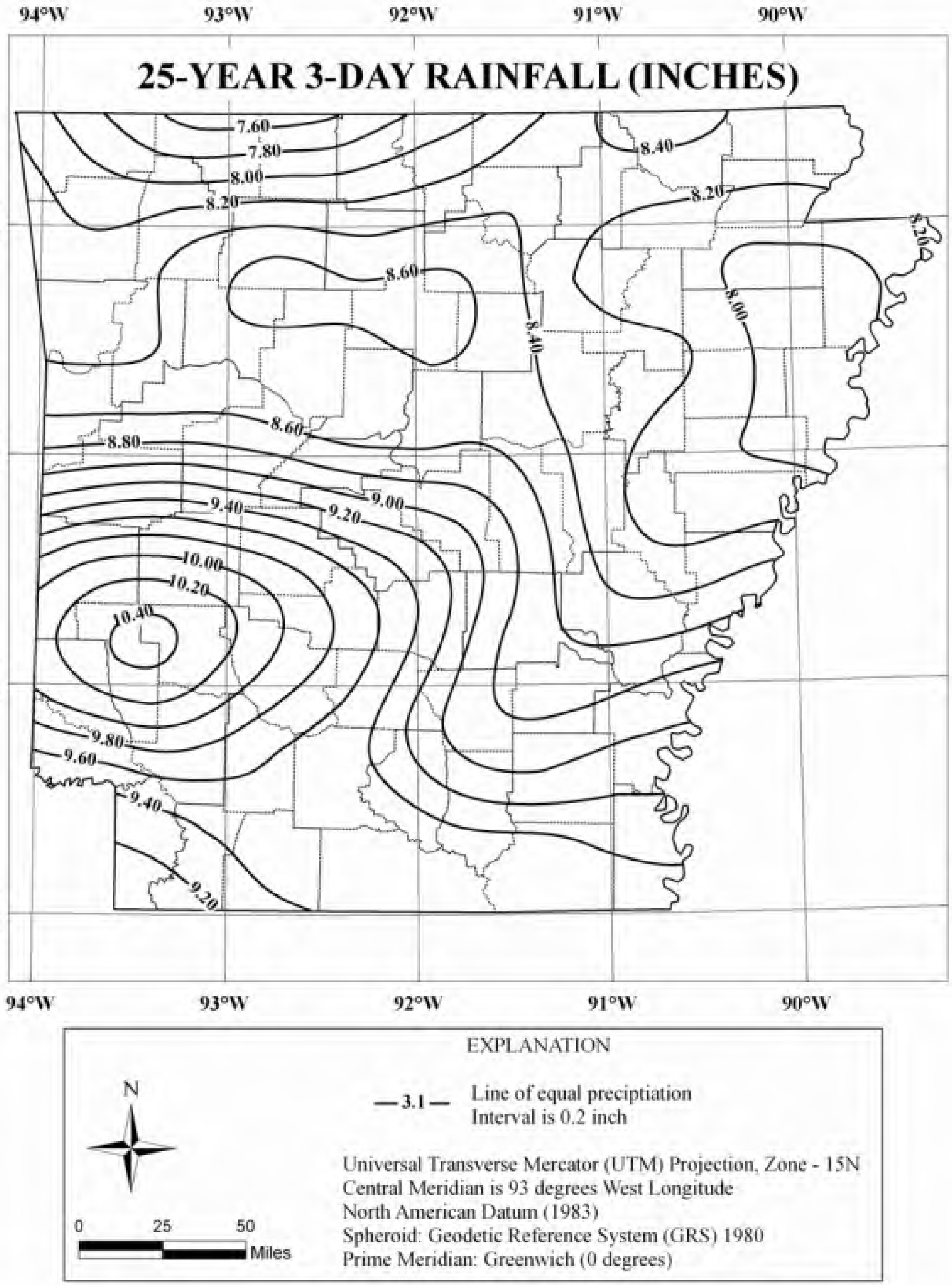

Figure 67. Depth of 25-year storm for 3-day interval in Arkansas.

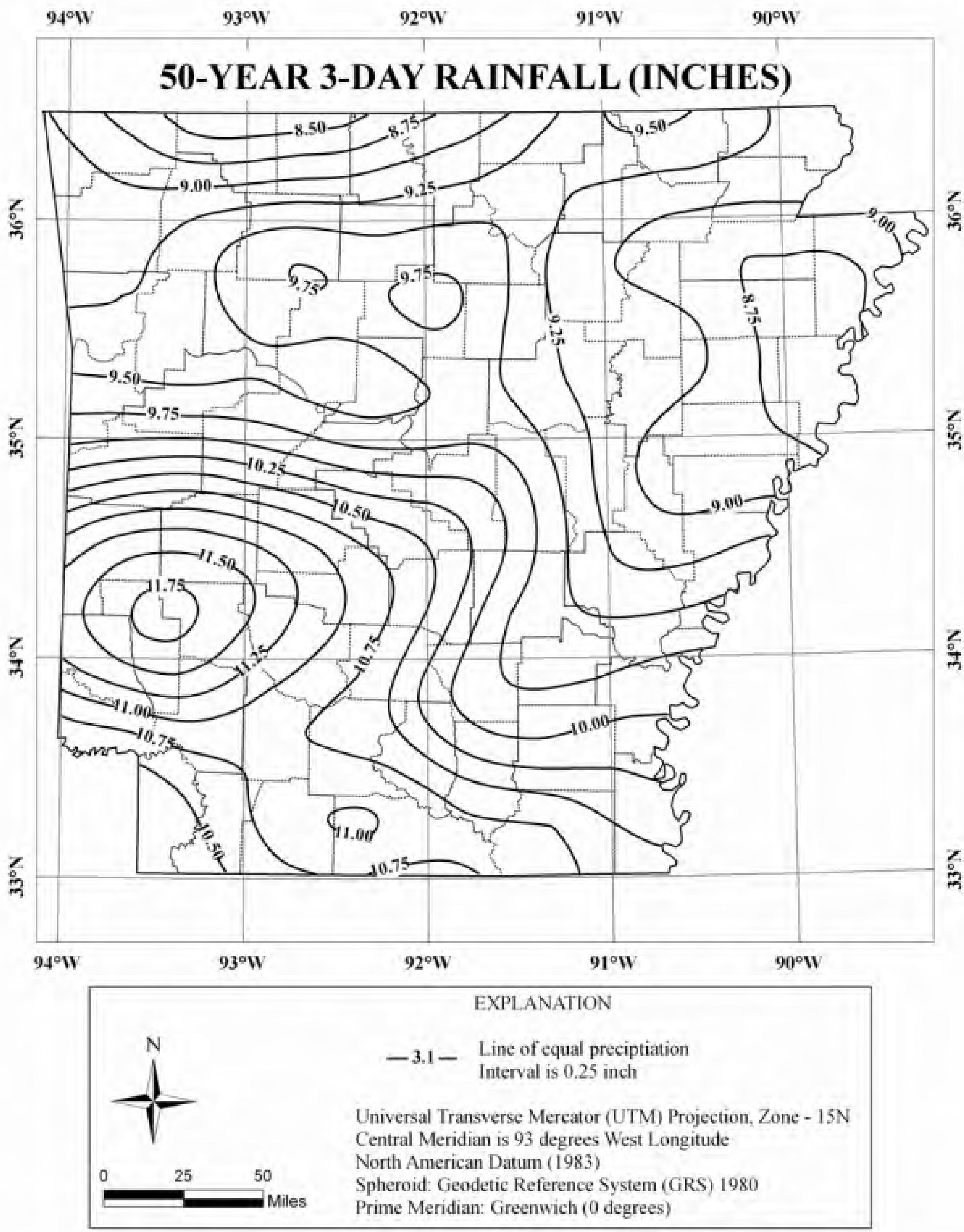

Figure 68. Depth of 50-year storm for 3-day interval in Arkansas.

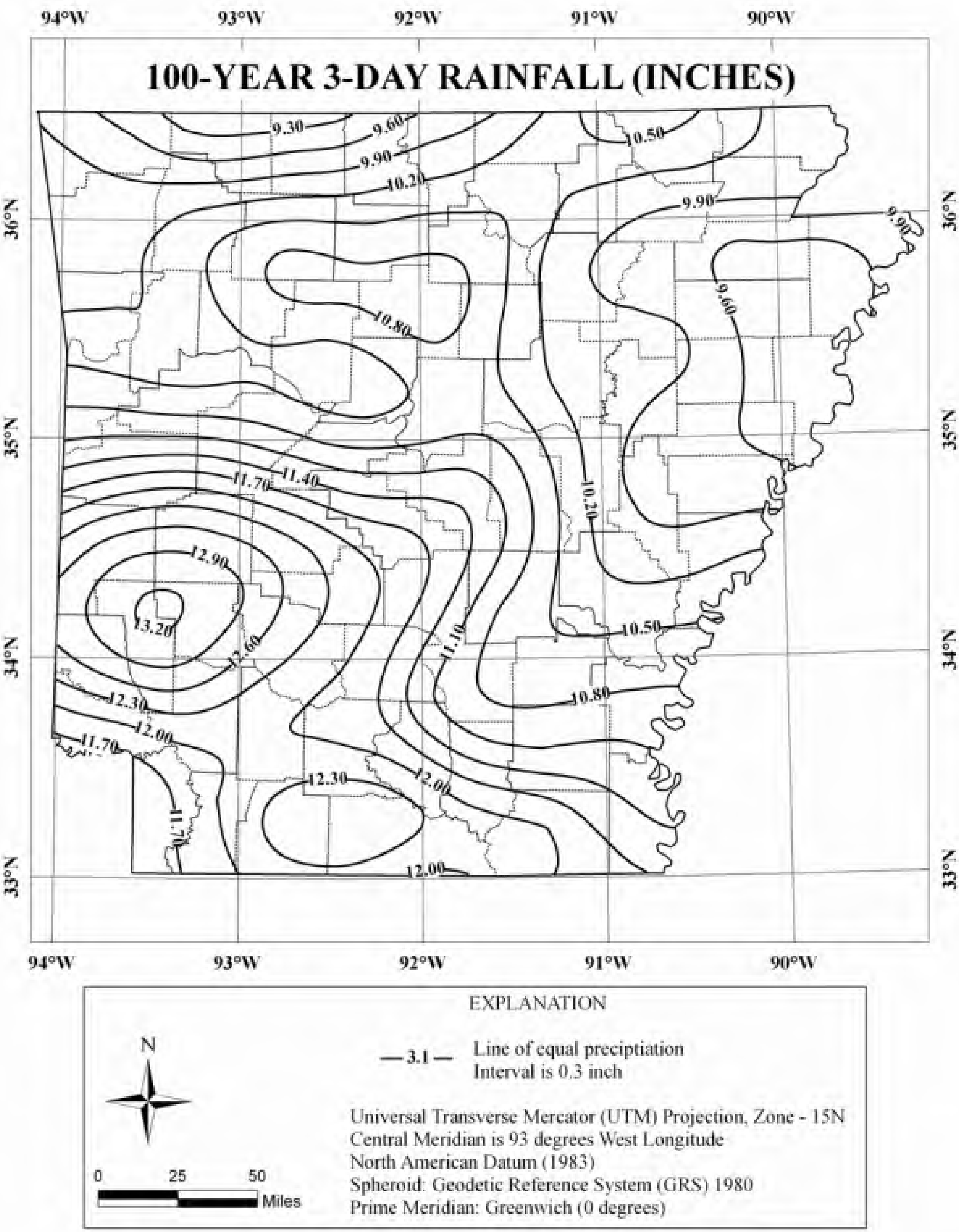

Figure 69. Depth of 100-year storm for 3-day interval in Arkansas.

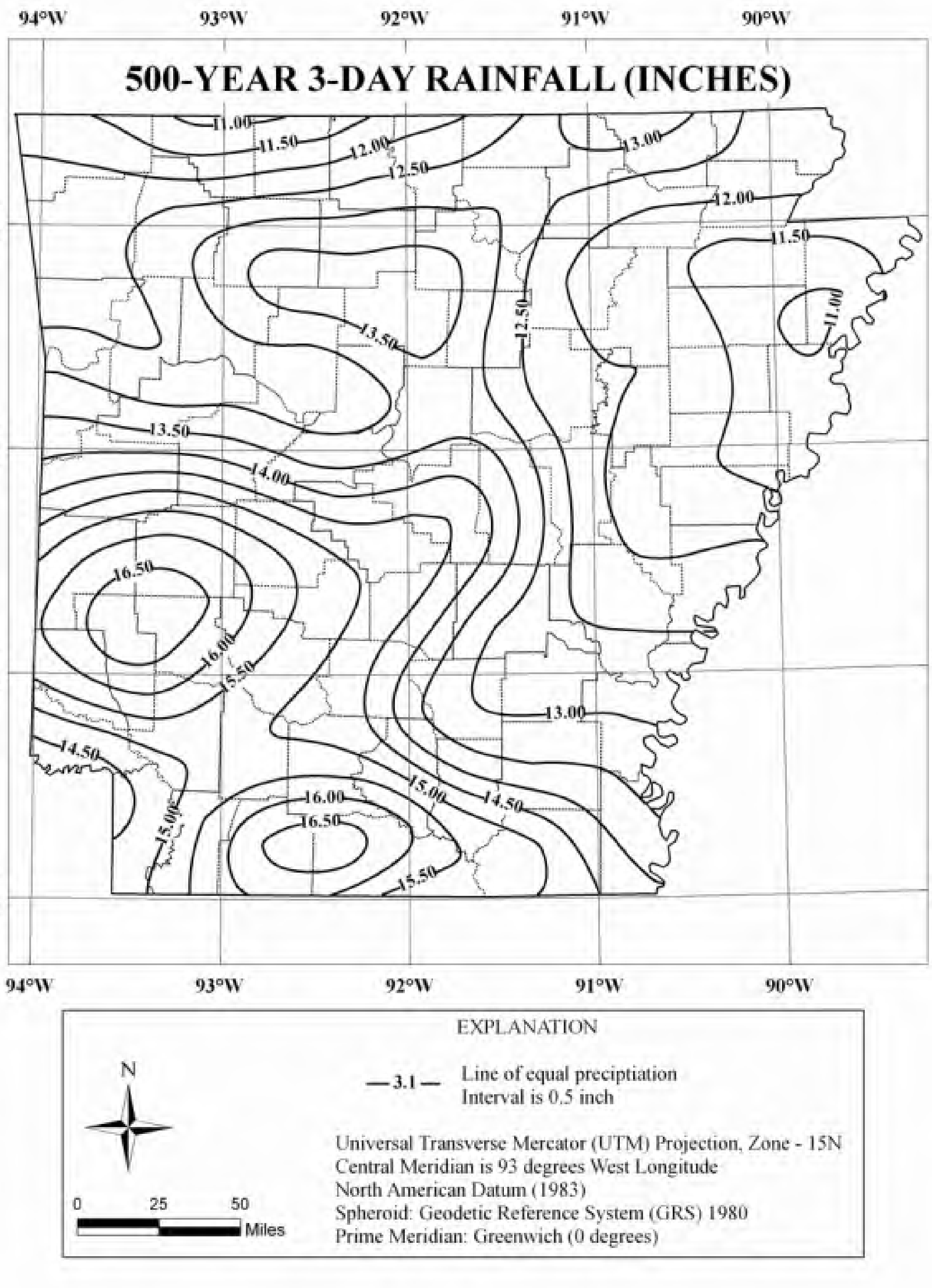

Figure 70. Depth of 500-year storm for 3-day interval in Arkansas.

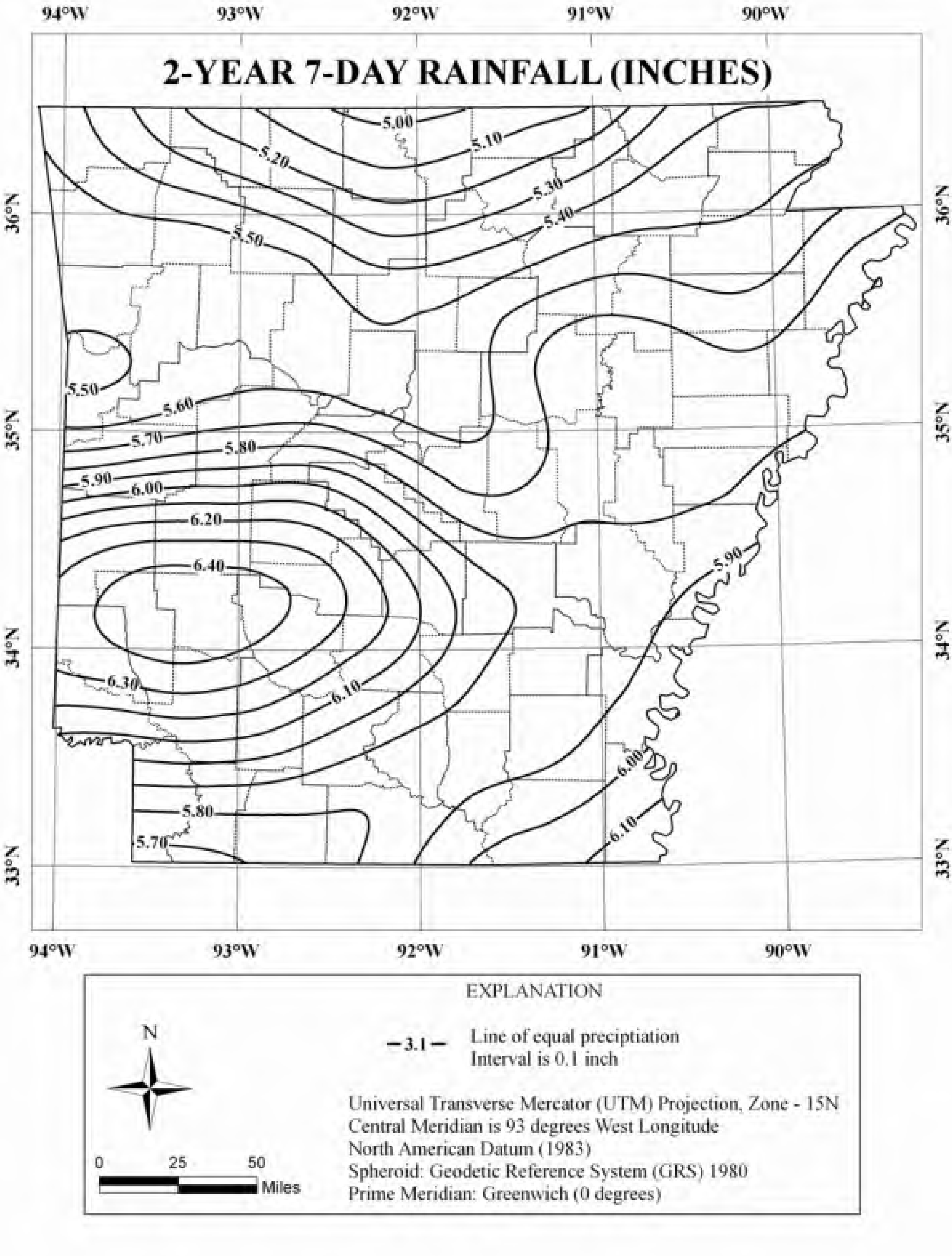

Figure 71. Depth of 2-year storm for 7-day interval in Arkansas.

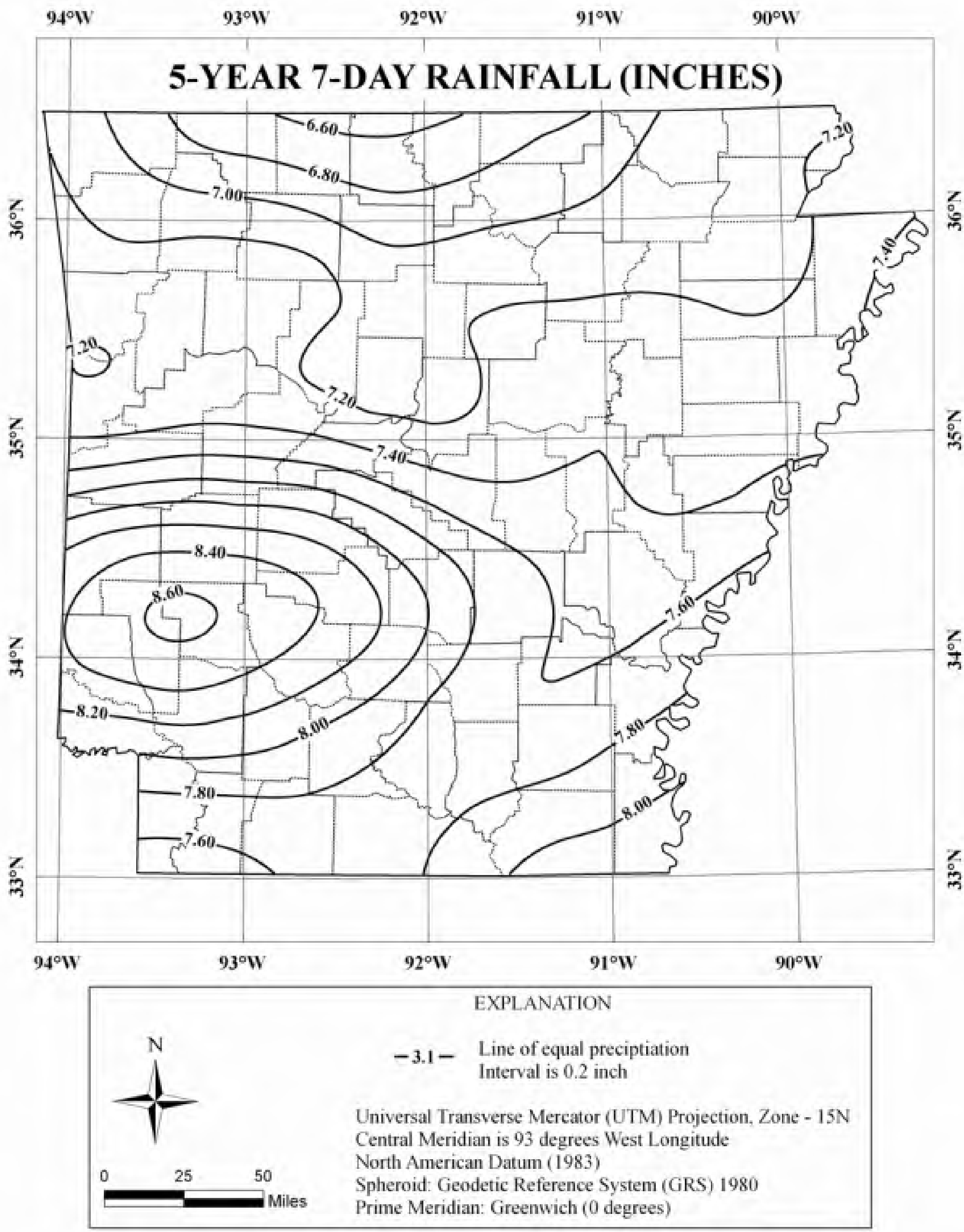

Figure 72. Depth of 5-year storm for 7-day interval in Arkansas.

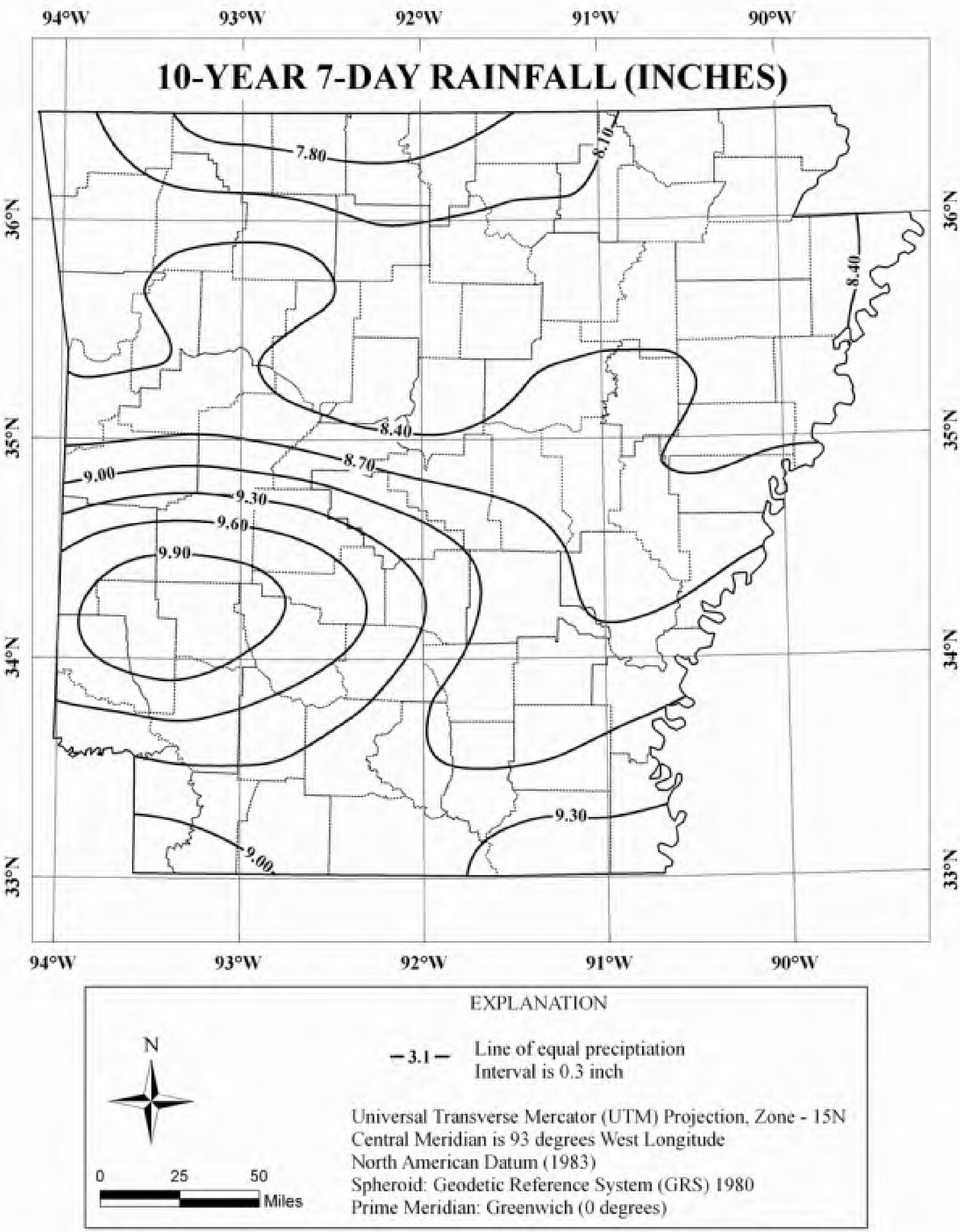

Figure 73. Depth of 10-year storm for 7-day interval in Arkansas.

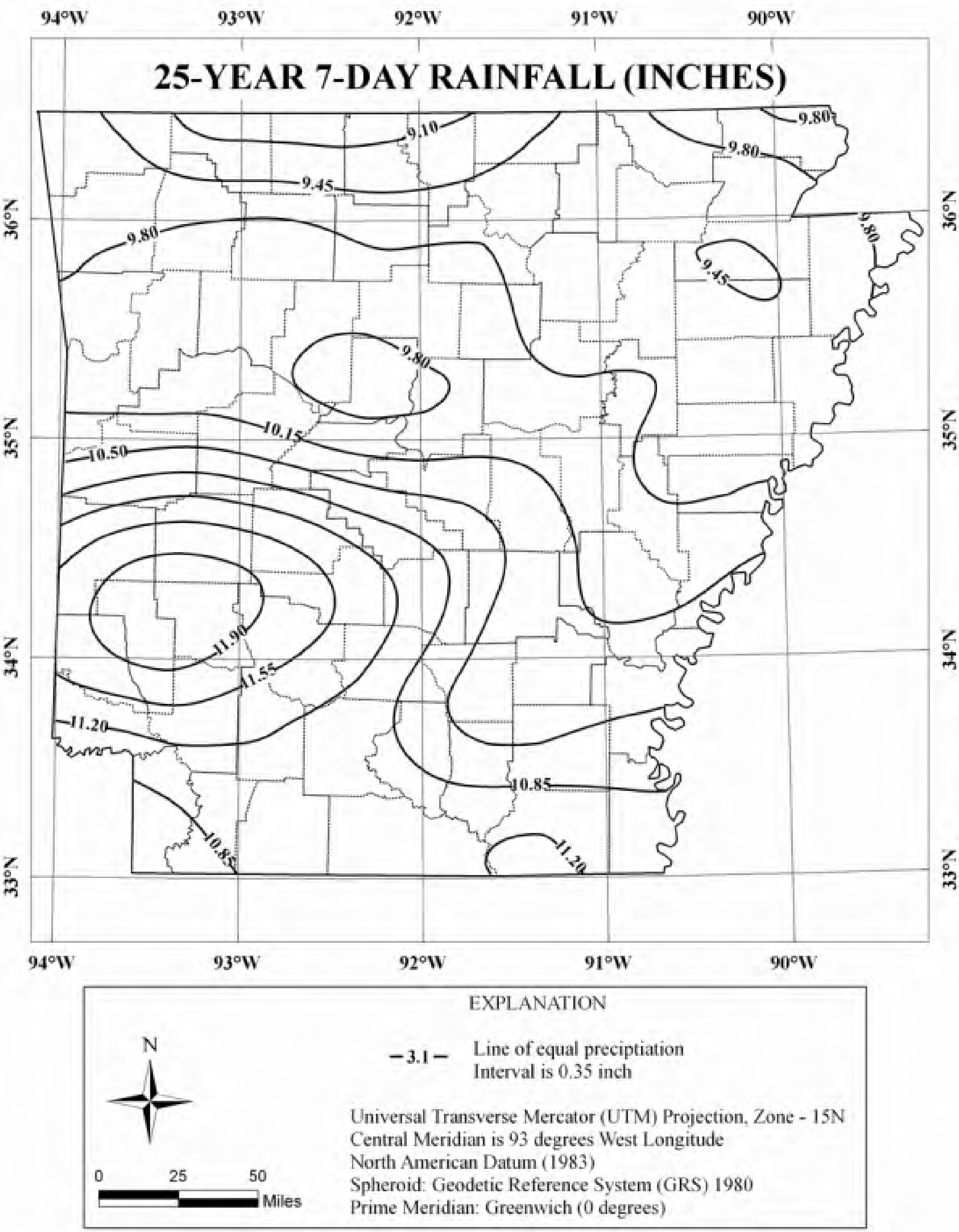

Figure 74. Depth of 25-year storm for 7-day interval in Arkansas.

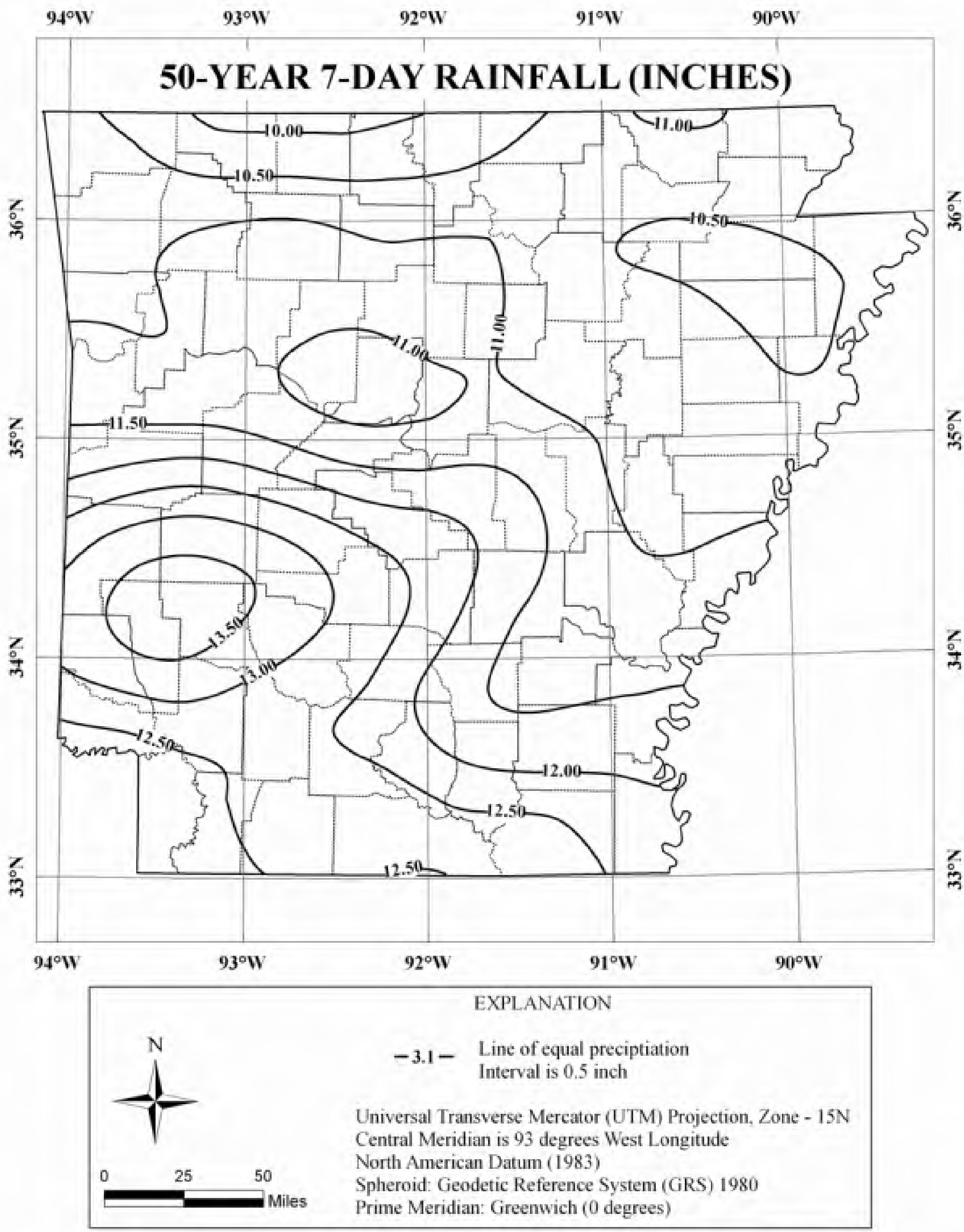

Figure 75. Depth of 50-year storm for 7-day interval in Arkansas.

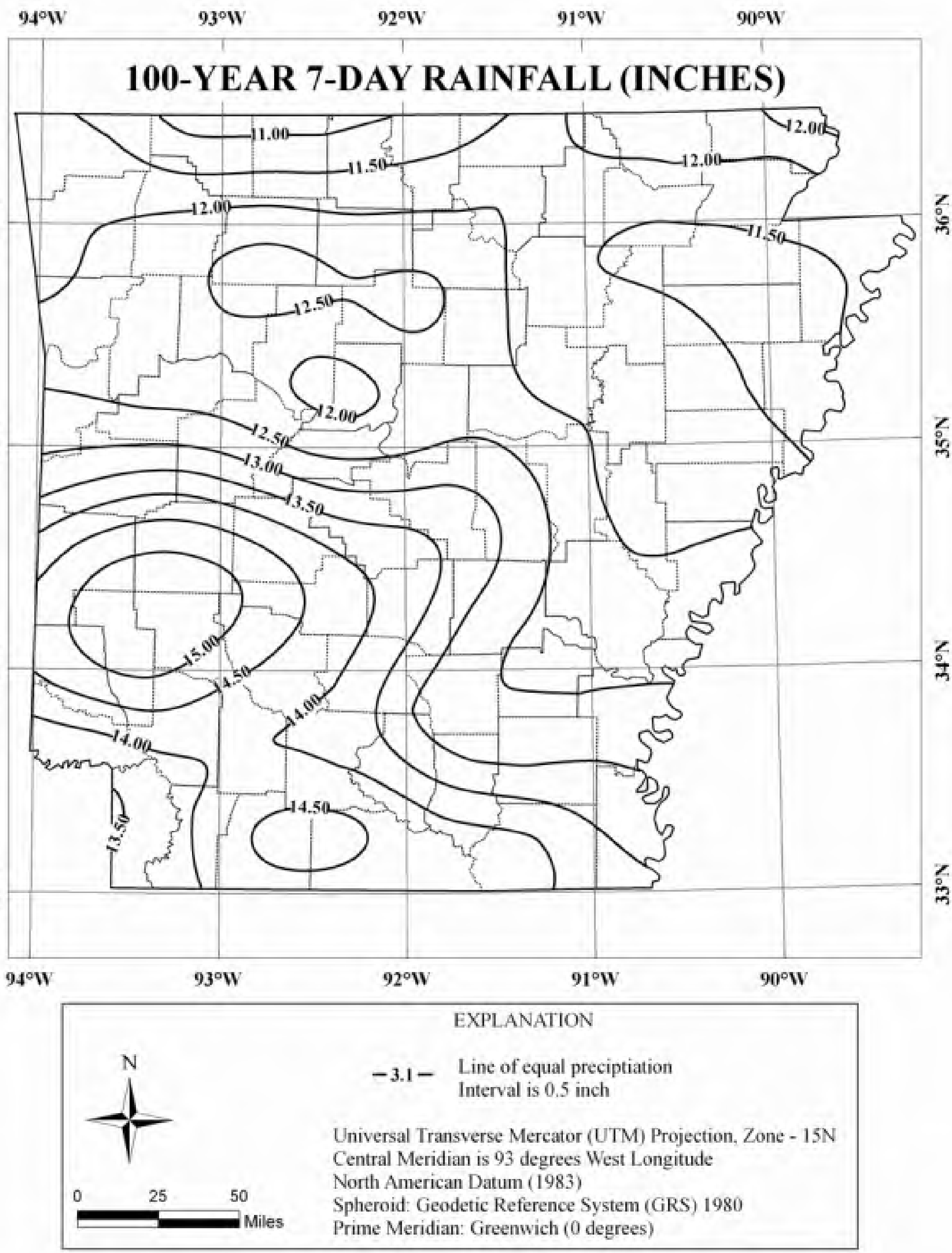

Figure 76. Depth of 100-year storm for 7-day interval in Arkansas.

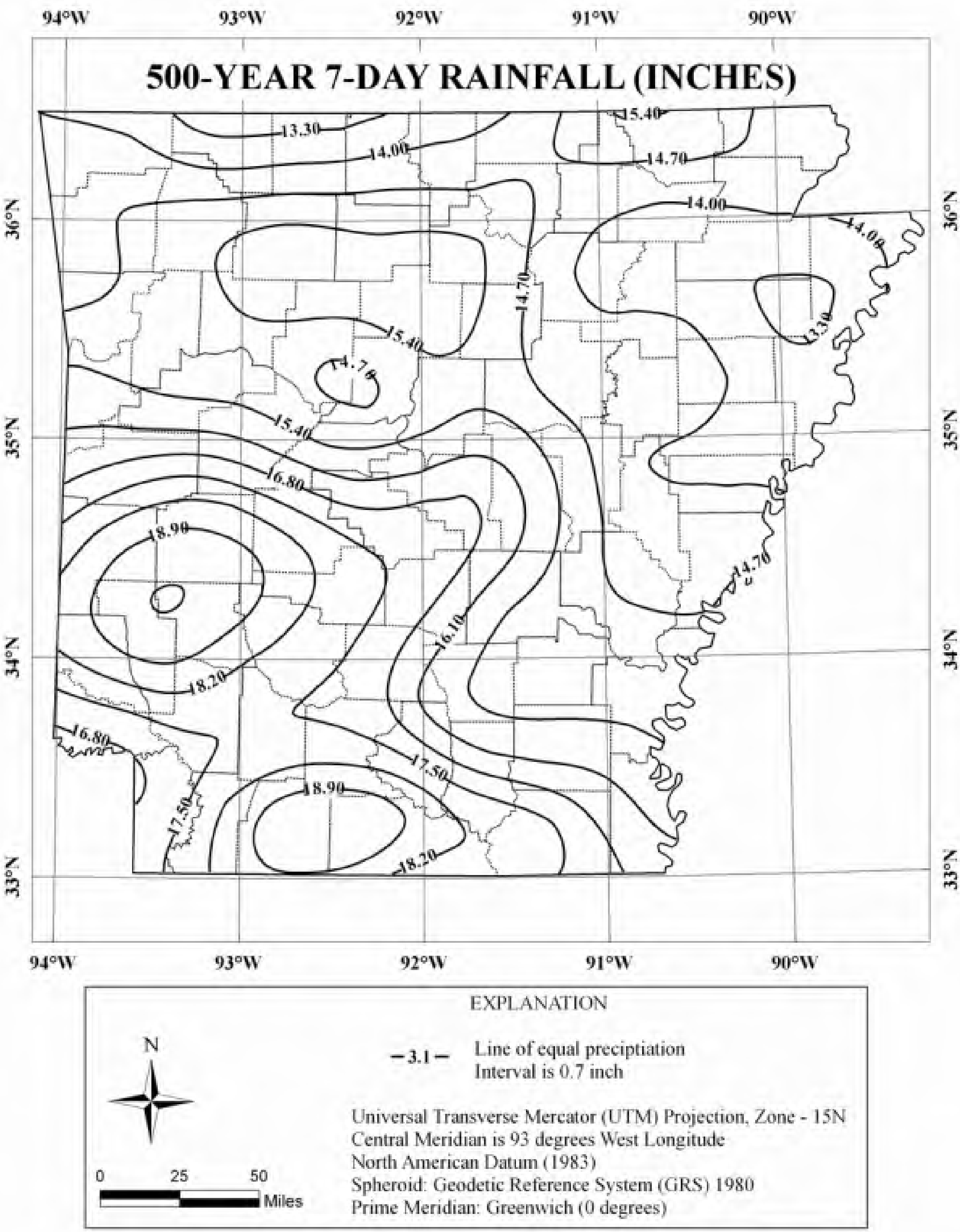

Figure 77. Depth of 500-year storm for 7-day interval in Arkansas.